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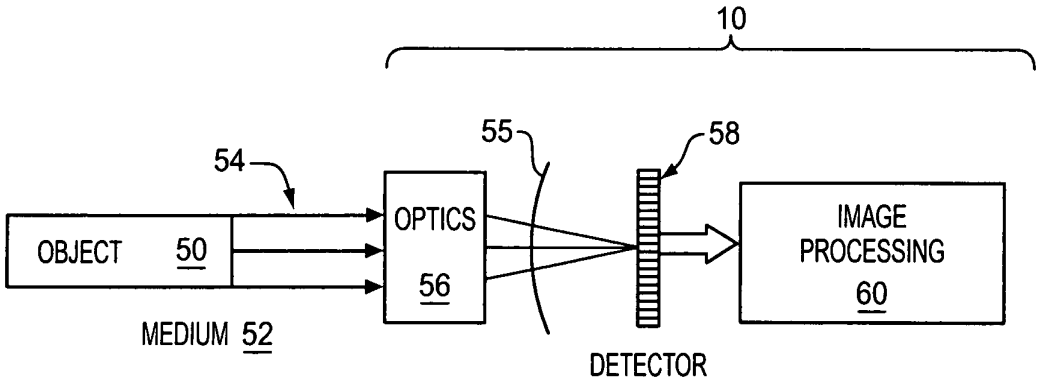


FIG. 1

PRIOR ART

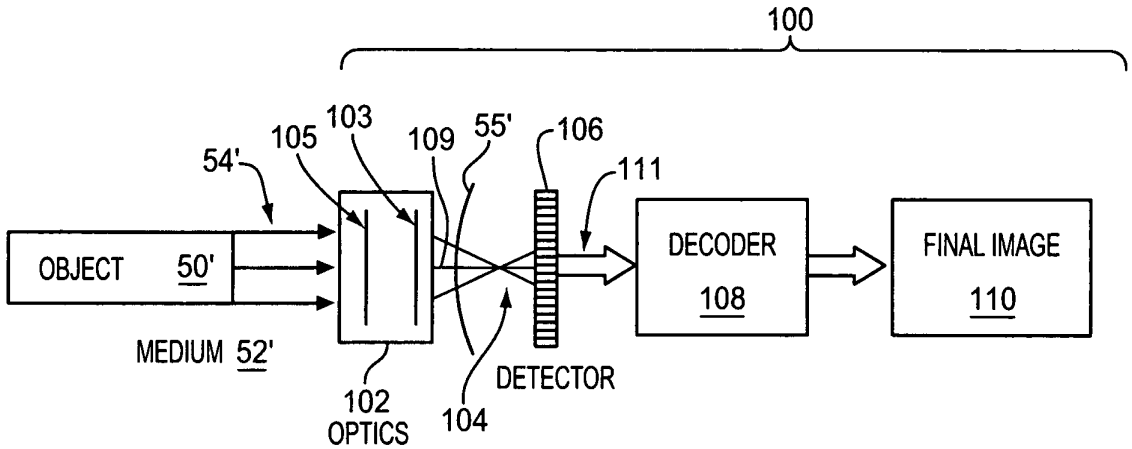


FIG. 2

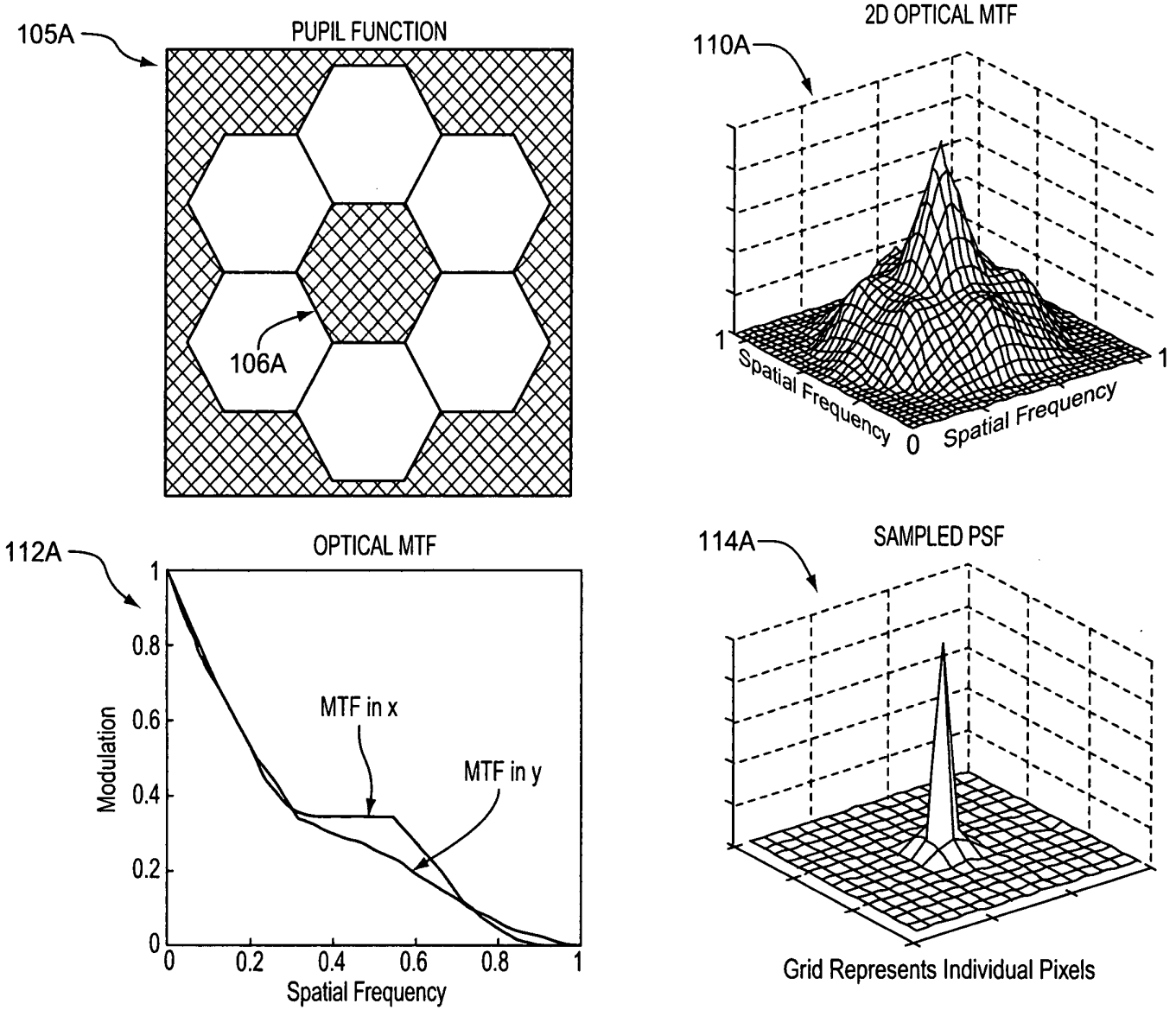

105A
PUPIL FUNCTION
106A
2D OPTICAL MTF
110A
1
Spatial Frequency
0
Spatial Frequency
1
112A
OPTICAL MTF
Modulation
MTF in x
MTF in y
0
0.2
0.4
0.6
0.8
1
Spatial Frequency
114A
SAMPLED PSF
Grid Represents Individual Pixels

FIG. 3

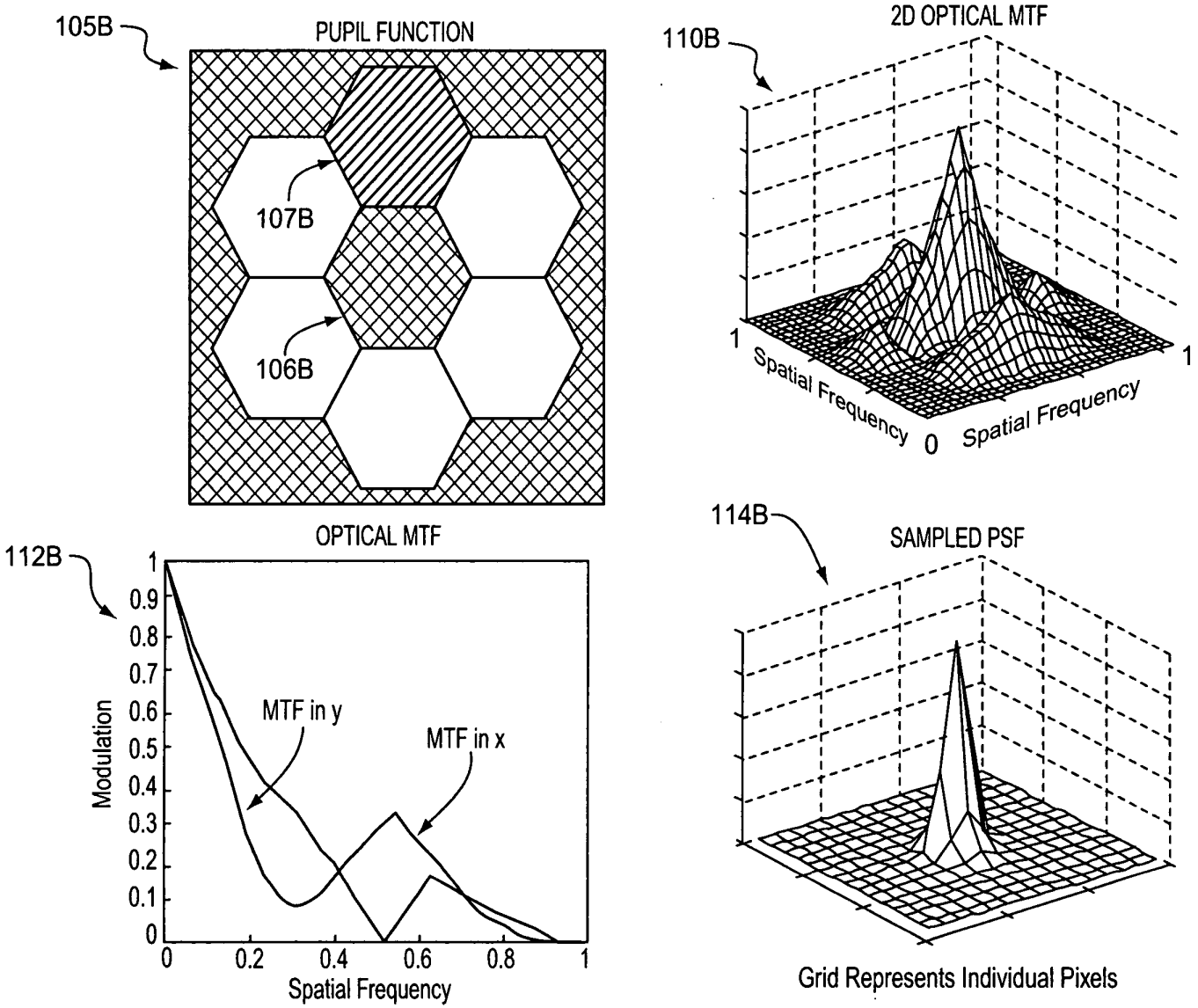

105B
PUPIL FUNCTION
107B
106B
110B
2D OPTICAL MTF
1
Spatial Frequency
0
Spatial Frequency
1
112B
OPTICAL MTF
Modulation
MTF in y
MTF in x
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
Spatial Frequency
114B
SAMPLED PSF
Grid Represents Individual Pixels

FIG. 4

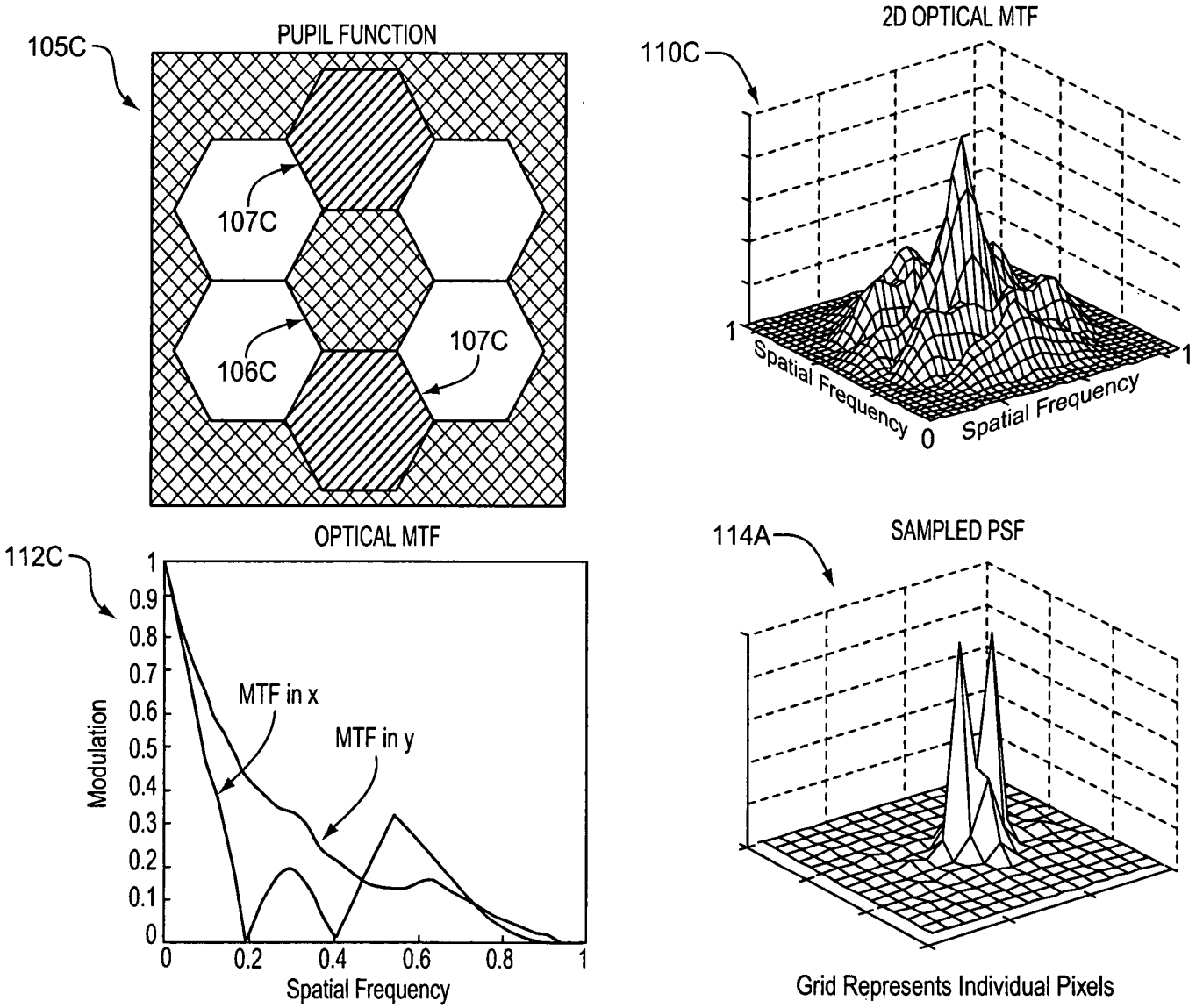

105C
PUPIL FUNCTION
107C
106C
107C
110C
2D OPTICAL MTF
1
Spatial Frequency
0
Spatial Frequency
1
112C
OPTICAL MTF
Modulation
MTF in x
MTF in y
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
Spatial Frequency
114A
SAMPLED PSF
Grid Represents Individual Pixels

FIG. 5

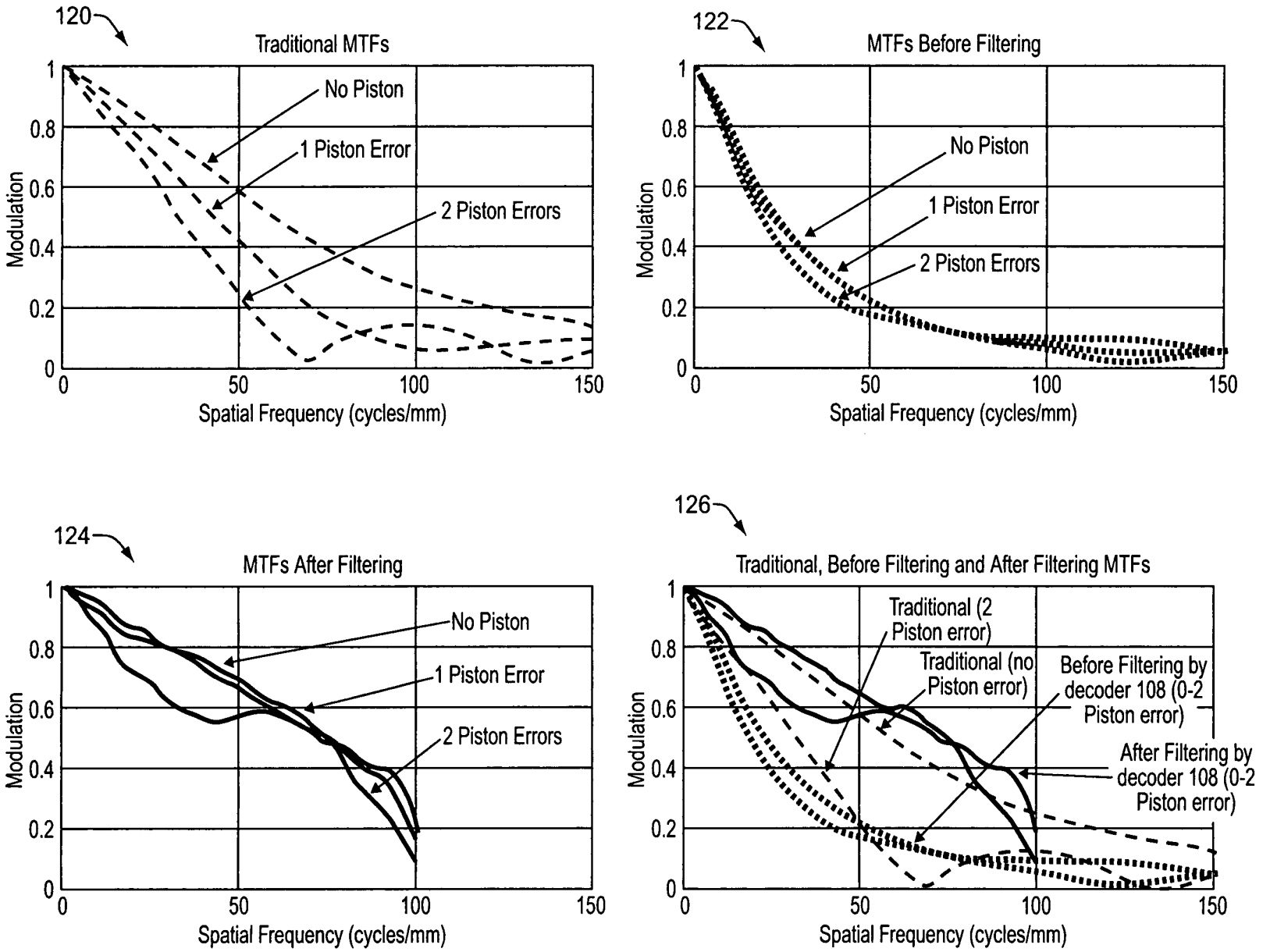

120
Traditional MTFs
No Piston
1 Piston Error
2 Piston Errors
Modulation
Spatial Frequency (cycles/mm)
122
MTFs Before Filtering
No Piston
1 Piston Error
2 Piston Errors
Modulation
Spatial Frequency (cycles/mm)
124
MTFs After Filtering
No Piston
1 Piston Error
2 Piston Errors
Modulation
Spatial Frequency (cycles/mm)
126
Traditional, Before Filtering and After Filtering MTFs
Traditional (2 Piston error)
Traditional (no Piston error)
Before Filtering by decoder 108 (0-2 Piston error)
After Filtering by decoder 108 (0-2 Piston error)
Modulation
Spatial Frequency (cycles/mm)

FIG. 6

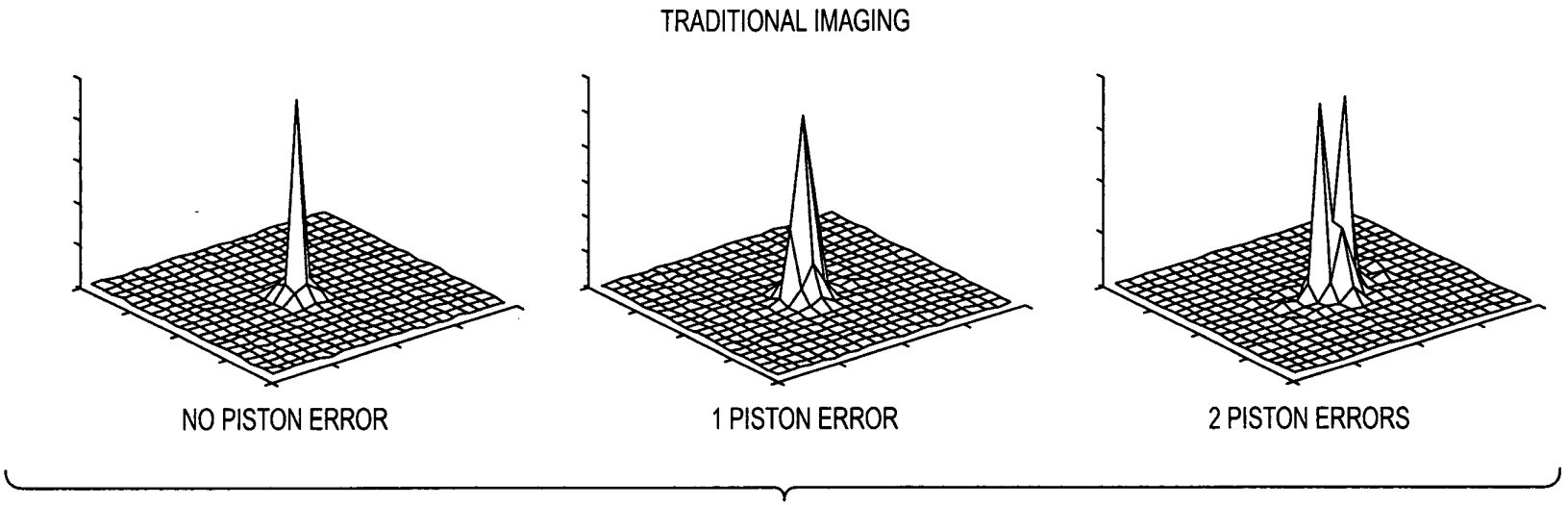

TRADITIONAL IMAGING
NO PISTON ERROR
1 PISTON ERROR
2 PISTON ERRORS

FIG. 7A

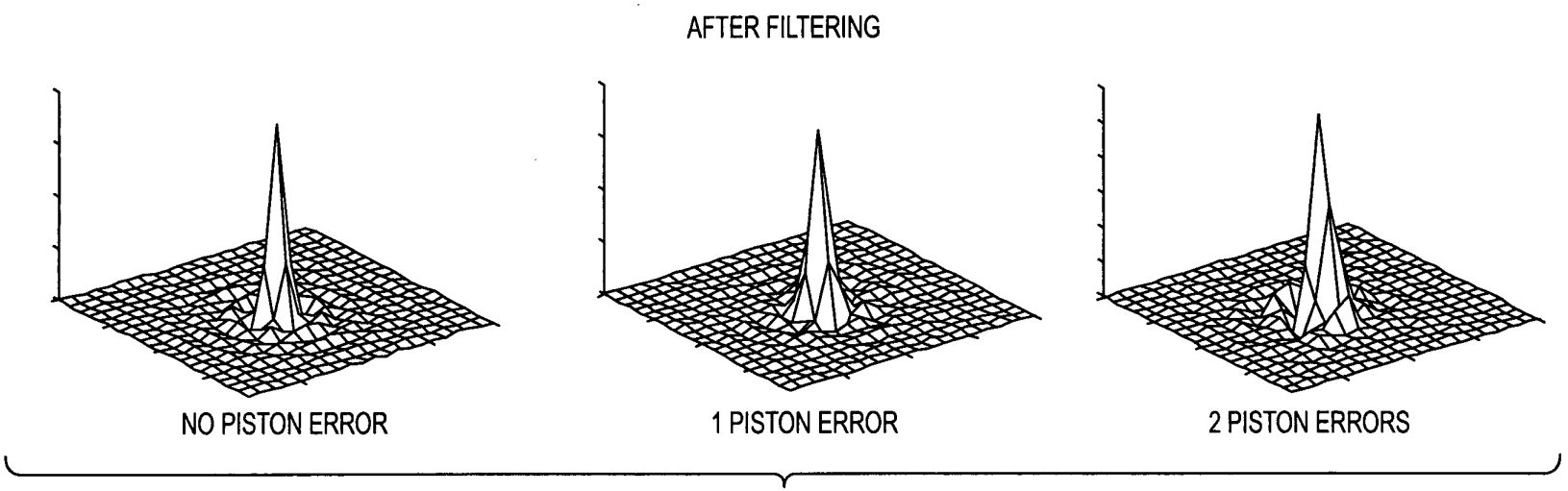

AFTER FILTERING
NO PISTON ERROR
1 PISTON ERROR
2 PISTON ERRORS

FIG. 7B

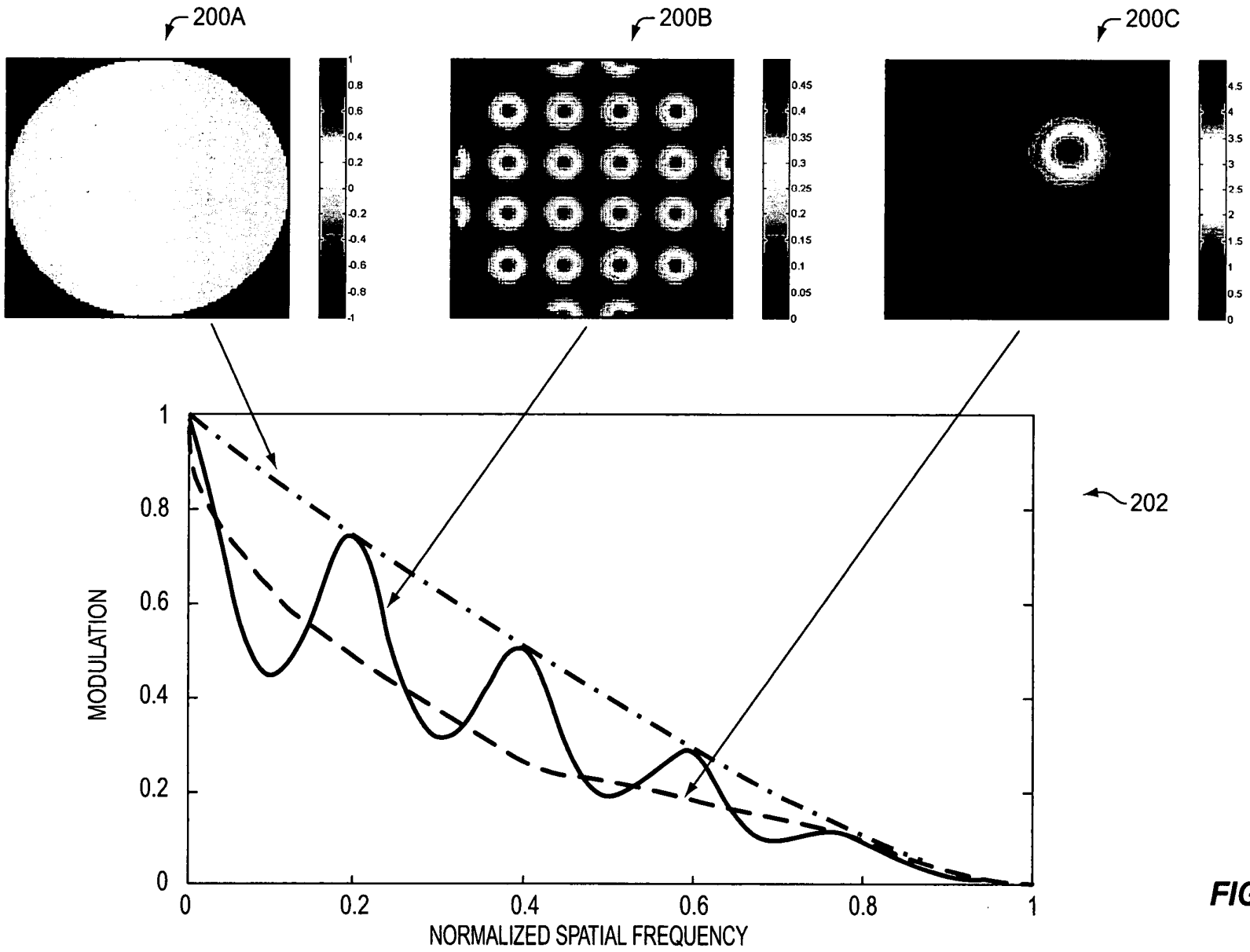

200A
200B
200C
202
MODULATION
NORMALIZED SPATIAL FREQUENCY
0
0.2
0.4
0.6
0.8
1

FIG. 8

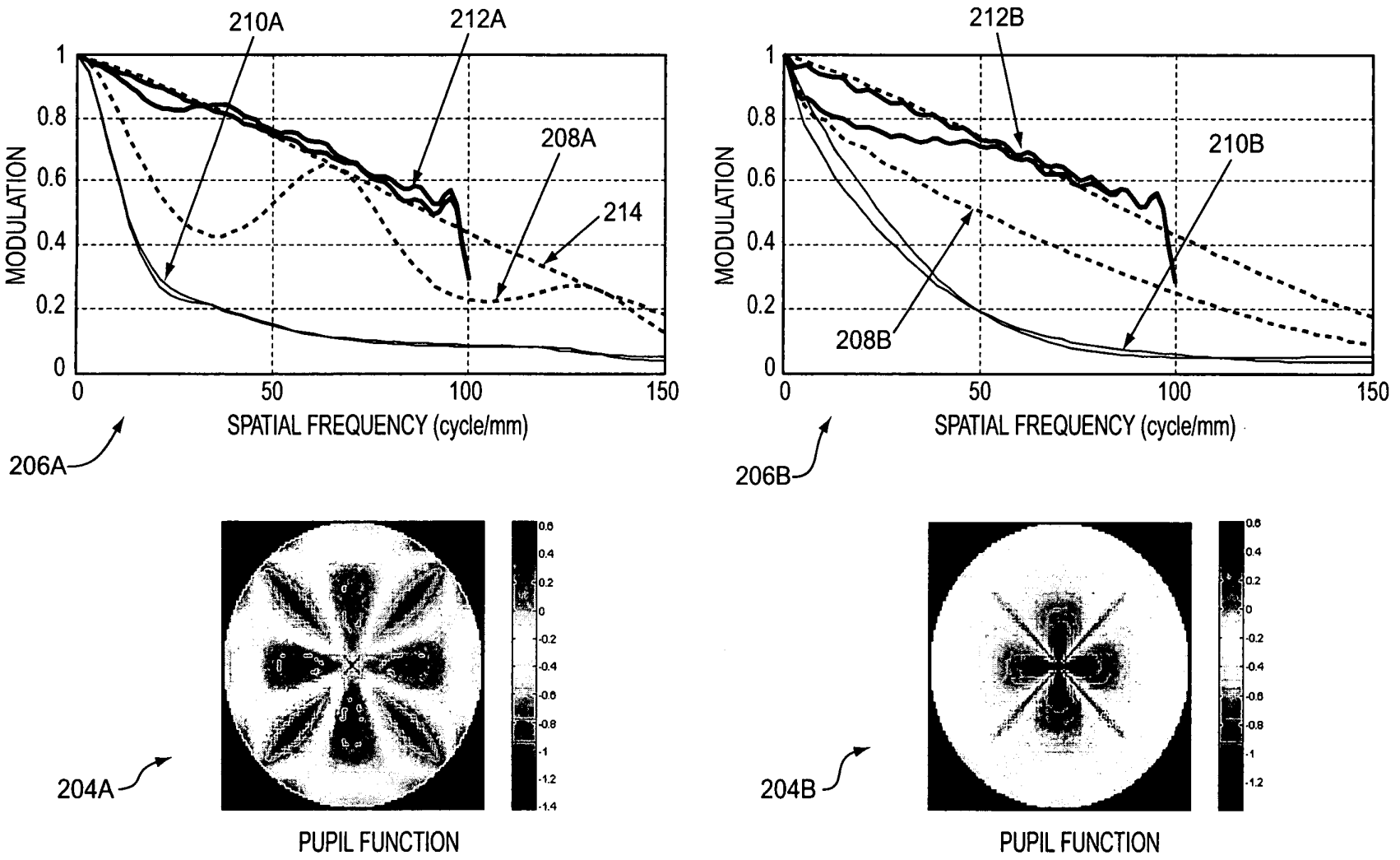
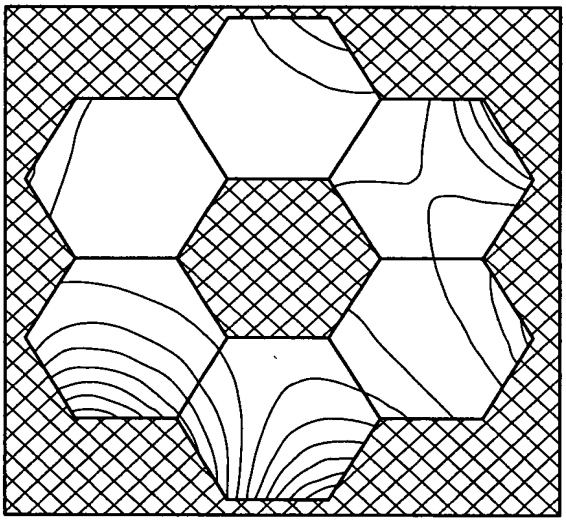

210A
212A
208A
214
MODULATION
SPATIAL FREQUENCY (cycle/mm)
206A
212B
210B
208B
206B
204A
PUPIL FUNCTION
204B
PUPIL FUNCTION

FIG. 9

FIG. 10

PUPIL FUNCTION



FIRST ORDER OPTICAL PARAMETERS

2-meter collecting aperture
12-meter focal length
5-μm pixel size
100% fill factor
0.5 μm wavelength

Phase function is a Zernike polynomial with the following weights

#	Mathematical Form	Weight	#	Mathematical Form	Weight
0	1	0	11	$(4\rho^2 - 3)\rho^2 \cos 2\theta$	0.0379
1	$\rho \cos\theta$	0	12	$(4\rho^2 - 3)\rho^2 \sin 2\theta$	-0.1151
2	$\rho \sin\theta$	0	13	$\rho^4 \cos 4\theta$	0.5730
3	$2\rho^2 - 1$	-0.1914	14	$\rho^4 \sin 4\theta$	0.2412
4	$\rho^2 \cos 2\theta$	-0.3986	15	$(4\rho^4-12\rho^2+3)\rho \cos\theta$	-0.3050
5	$\rho^2 \sin 2\theta$	0.0290	16	$(4\rho^4-12\rho^2+3)\rho \sin\theta$	-0.1698
6	$(3\rho^2 - 2)\rho \cos\theta$	0.1073	17	$(5\rho^5-4\rho^3)\cos 3\theta$	0.0589
7	$(3\rho^2 - 2)\rho \sin\theta$	-0.0336	18	$(5\rho^5-4\rho^3)\sin 3\theta$	-0.0965
8	$\rho^3 \cos 3\theta$	0.0496	19	$\rho^5 \cos 5\theta$	0.7186
9	$\rho^3 \sin 3\theta$	-0.0562	20	$\rho^5 \sin 5\theta$	-0.5219
10	$6\rho^4 - 6\rho^2 + 1$	-0.2093			

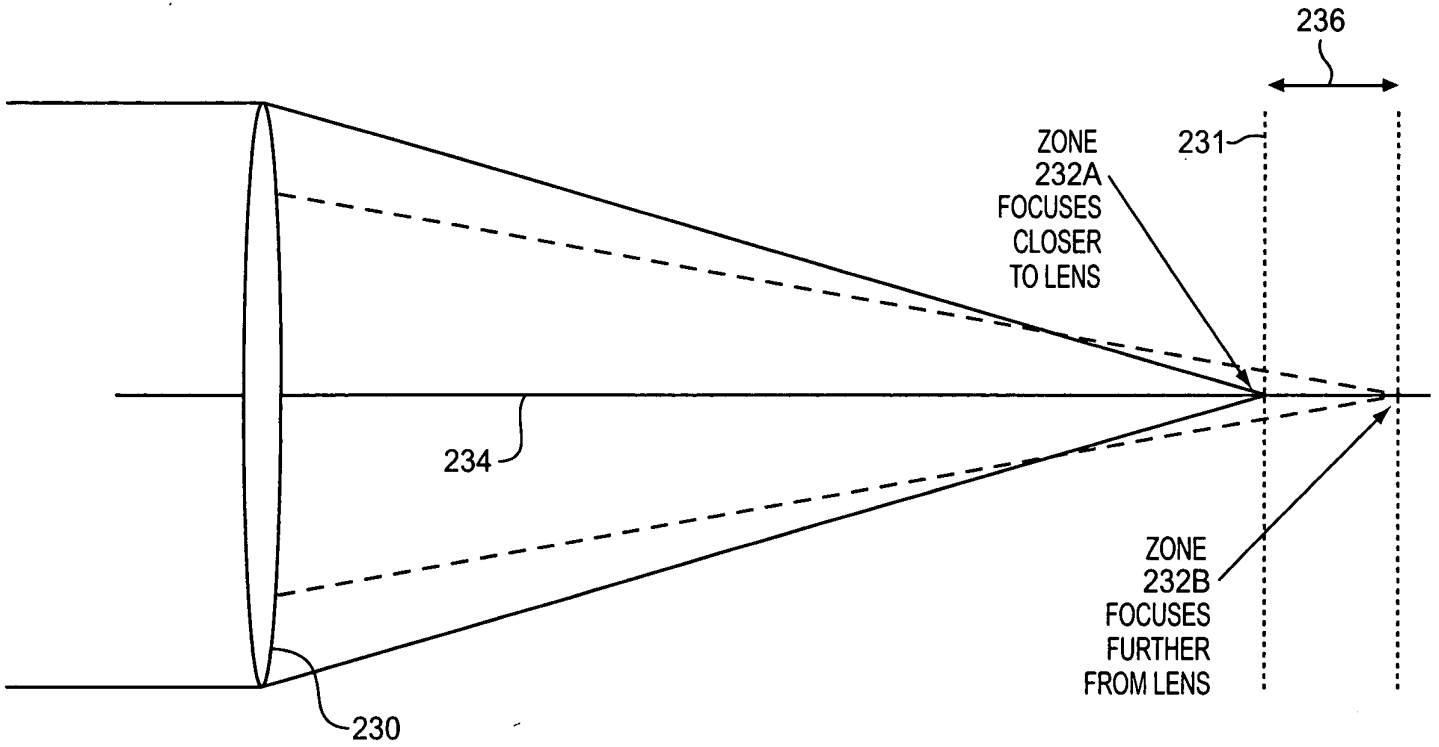

236
231
ZONE
232A
FOCUSES
CLOSER
TO LENS
234
ZONE
232B
FOCUSES
FURTHER
FROM LENS
230

FIG. 11

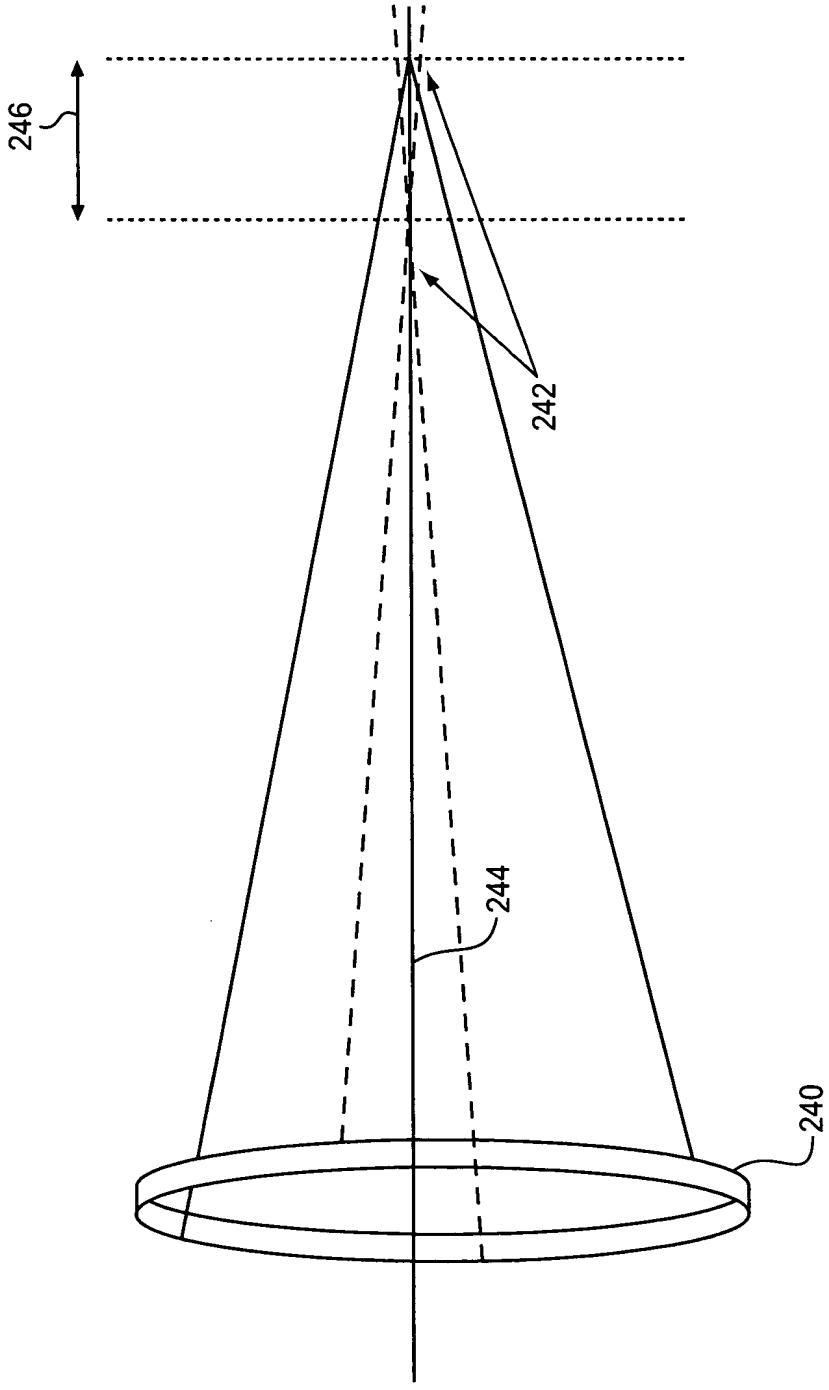


FIG. 12

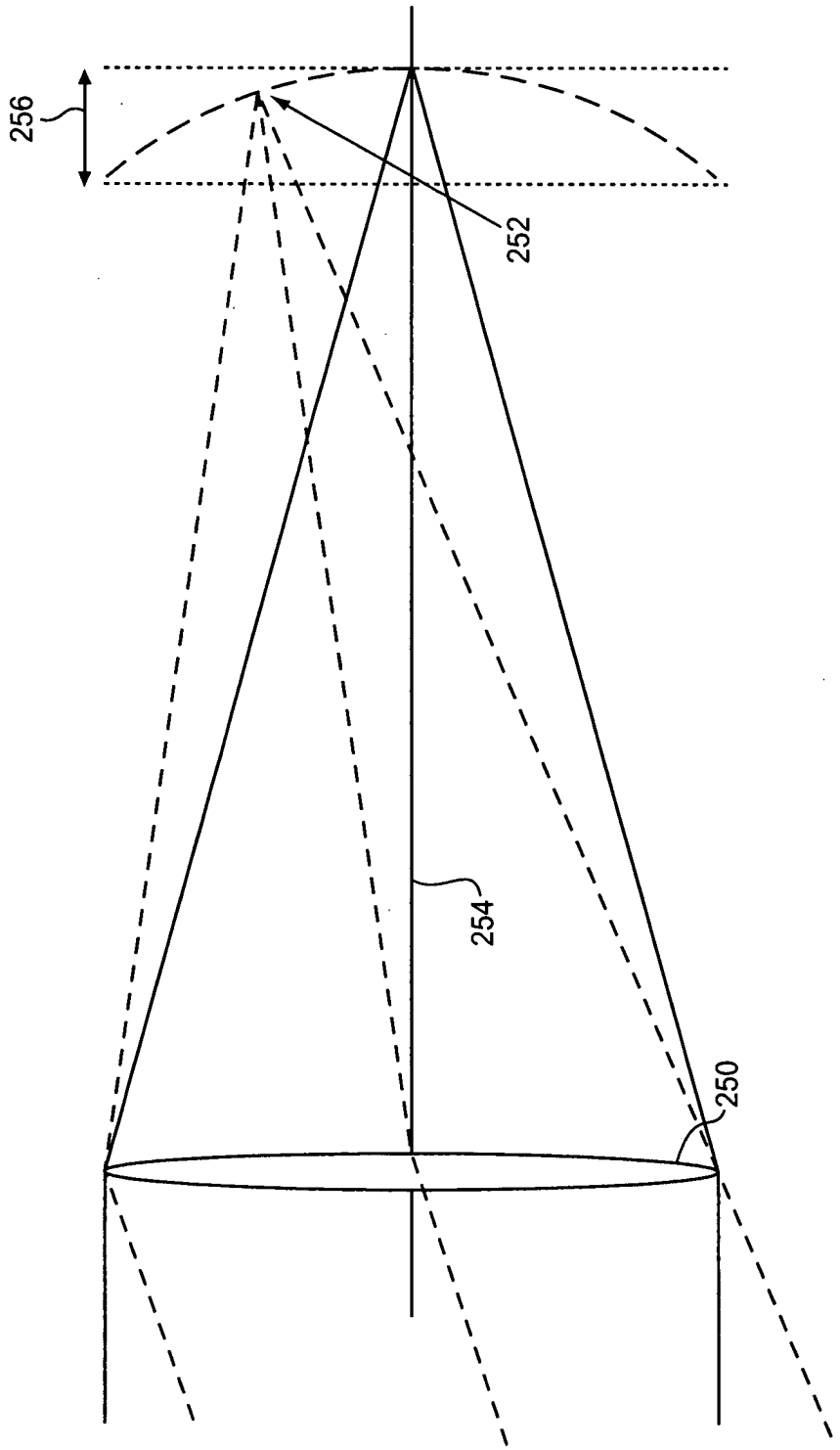


FIG. 13

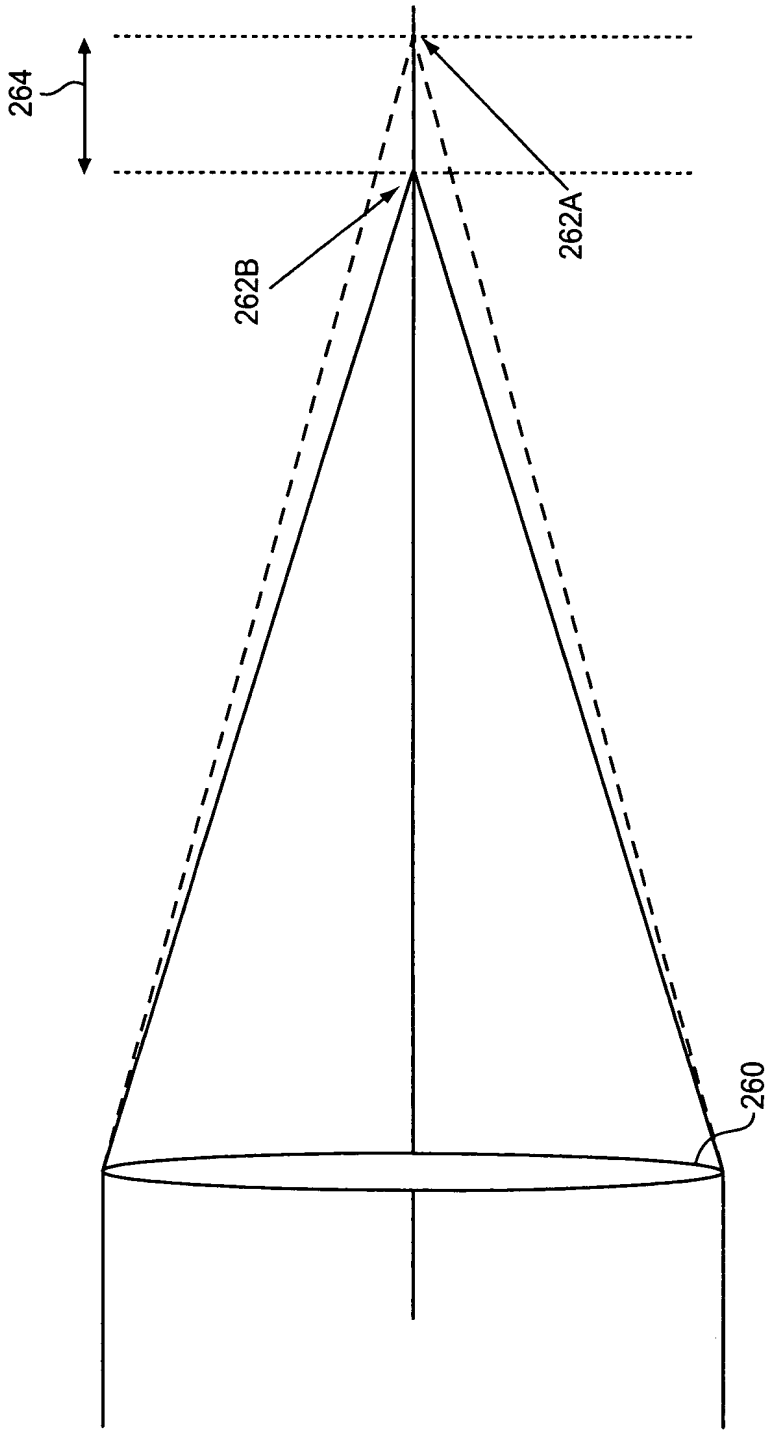


FIG. 14

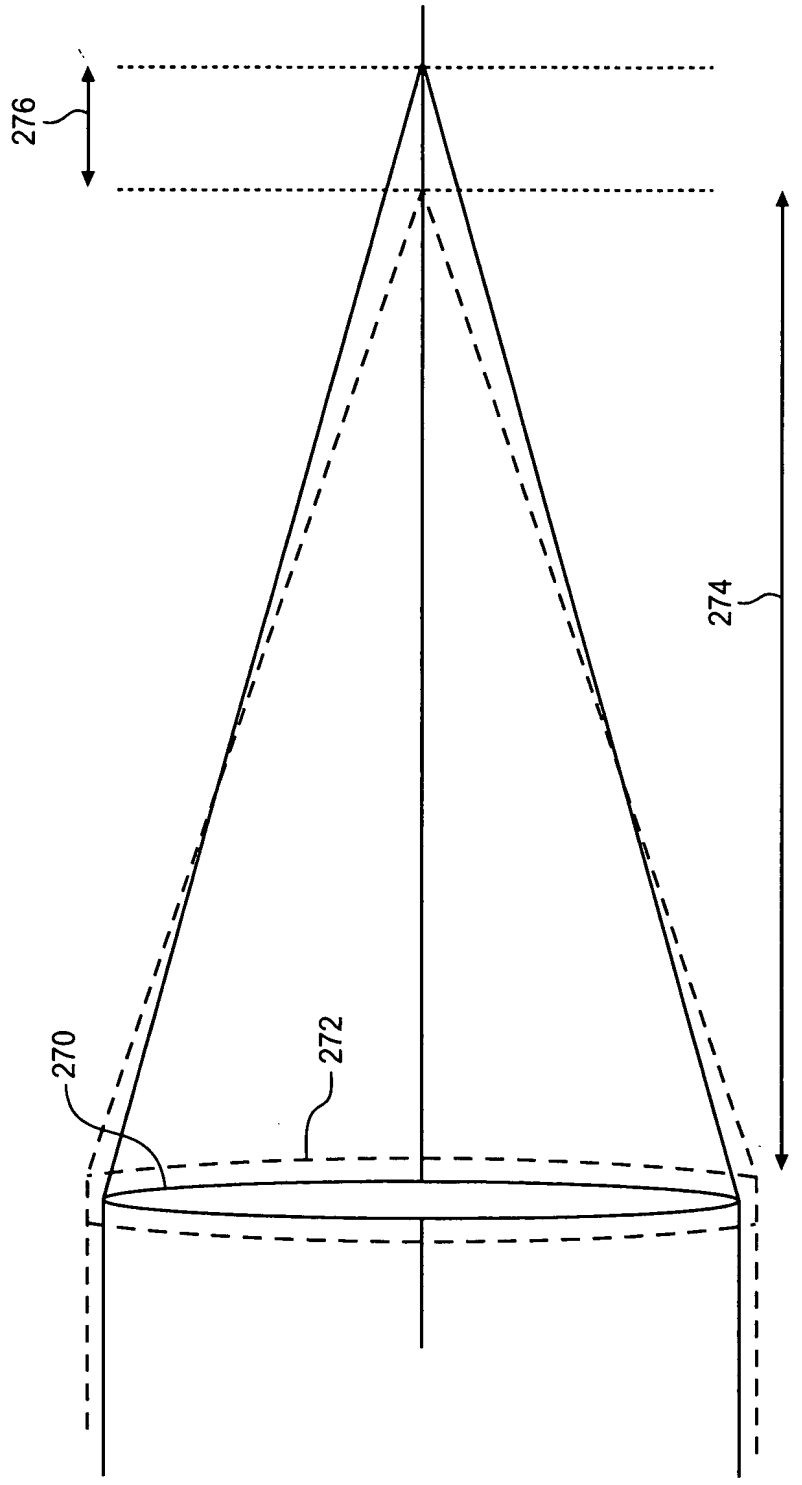


FIG. 15

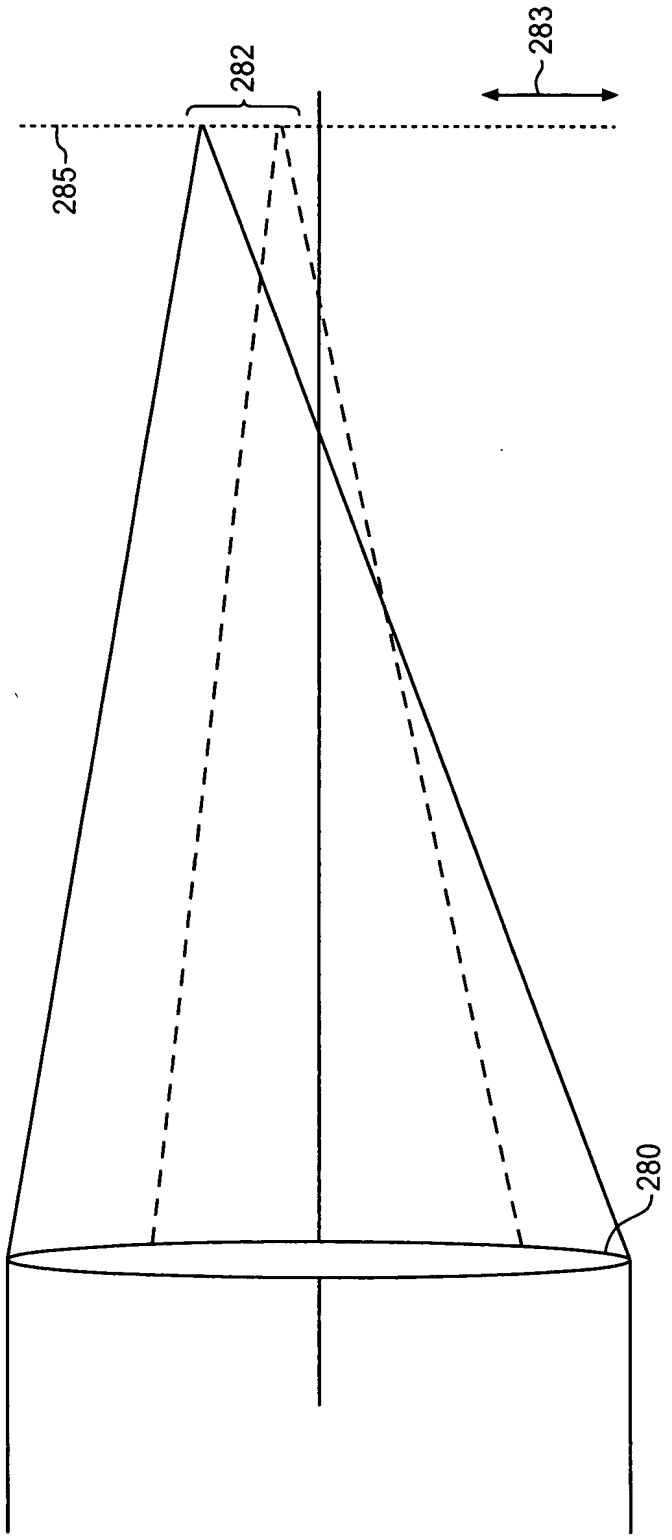


FIG. 16

FIG. 17

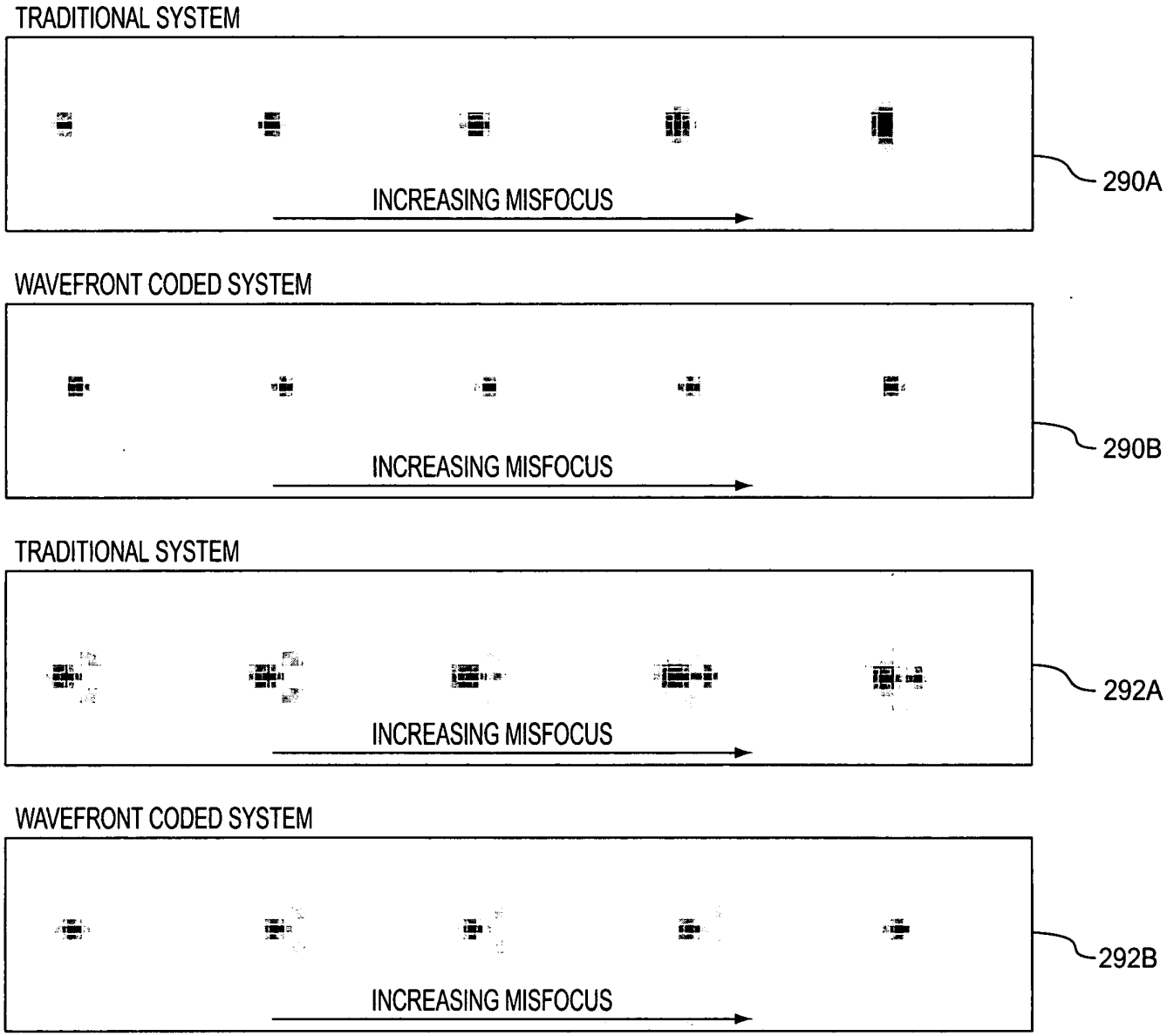
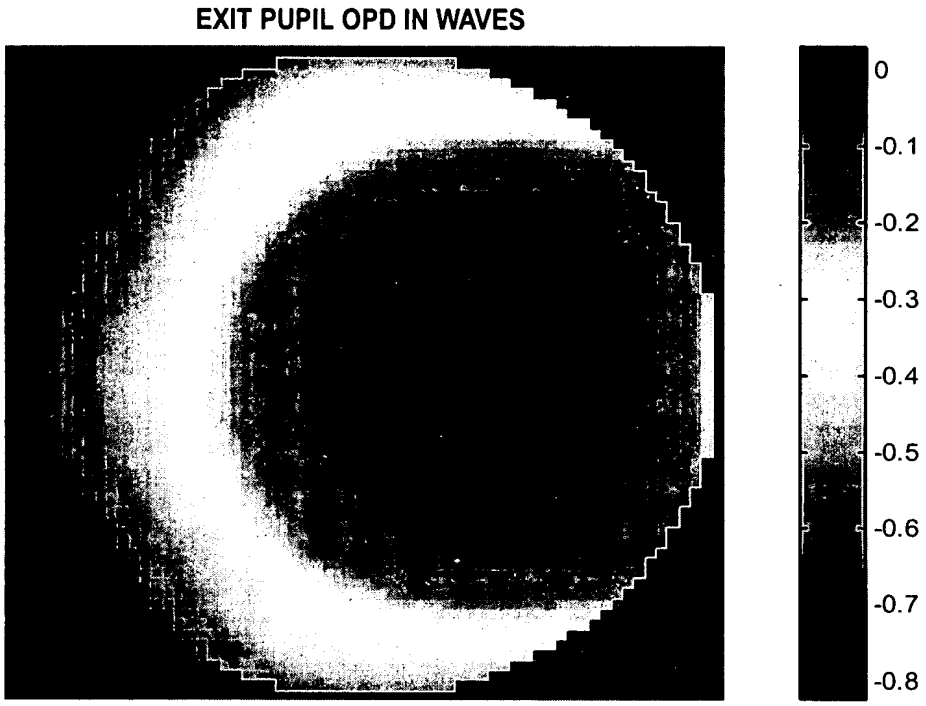

TRADITIONAL SYSTEM
INCREASING MISFOCUS
290A
WAVEFRONT CODED SYSTEM
INCREASING MISFOCUS
290B
TRADITIONAL SYSTEM
INCREASING MISFOCUS
292A
WAVEFRONT CODED SYSTEM
INCREASING MISFOCUS
292B

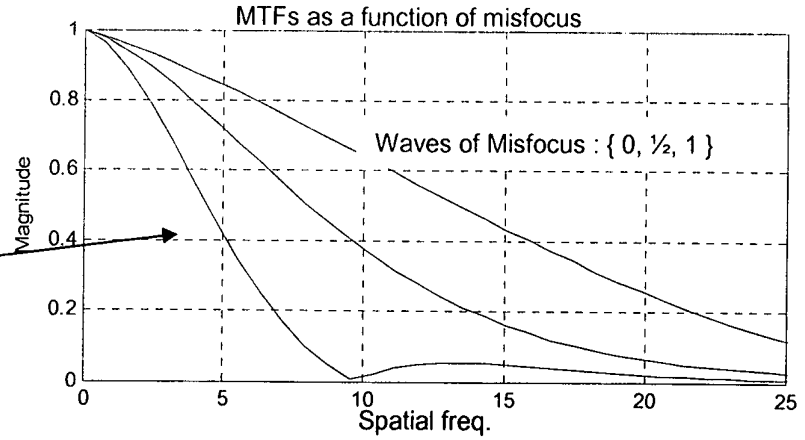
FIG. 17A



Weights	=	[-0.1837	-0.3292	0.3110	-0.0210	-0.0628]
Functional Form =	[	R	R^3	R^5	$R\cos(\theta)$	$R^3\cos(3\theta)$]

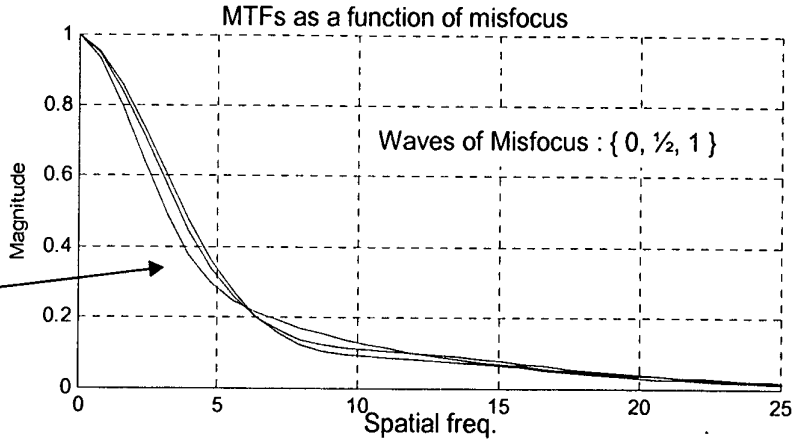
FIG. 17B

Diffraction-Limited System



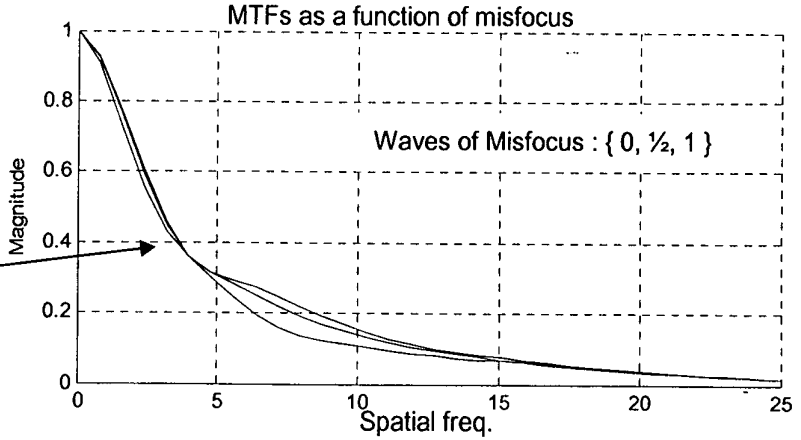
170A

Diffraction-Limited System
+ 1 wave peak-to-valley of
Trefoil aberration



170B

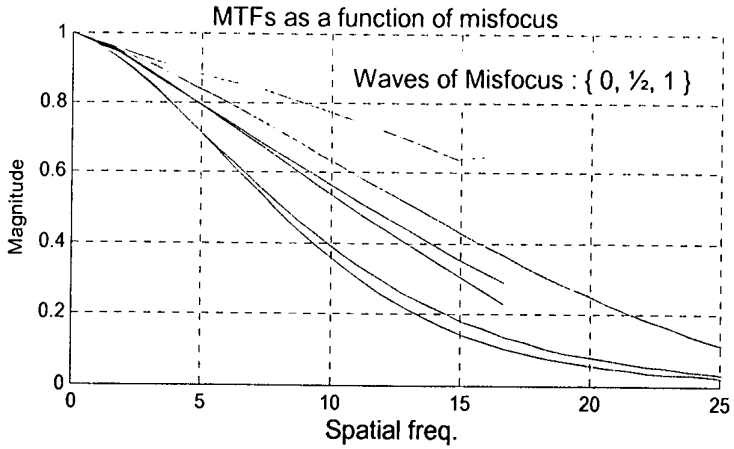
Diffraction-Limited System
+ 3 waves peak-to-valley of
Coma aberration



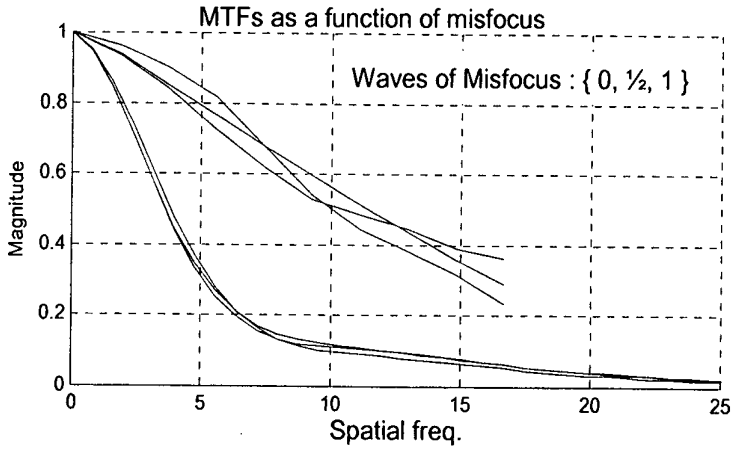
170C

FIG. 17C

171A



171B



171C

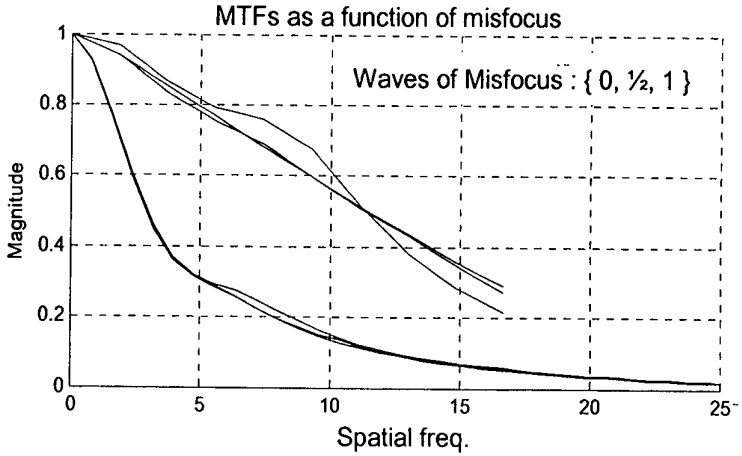
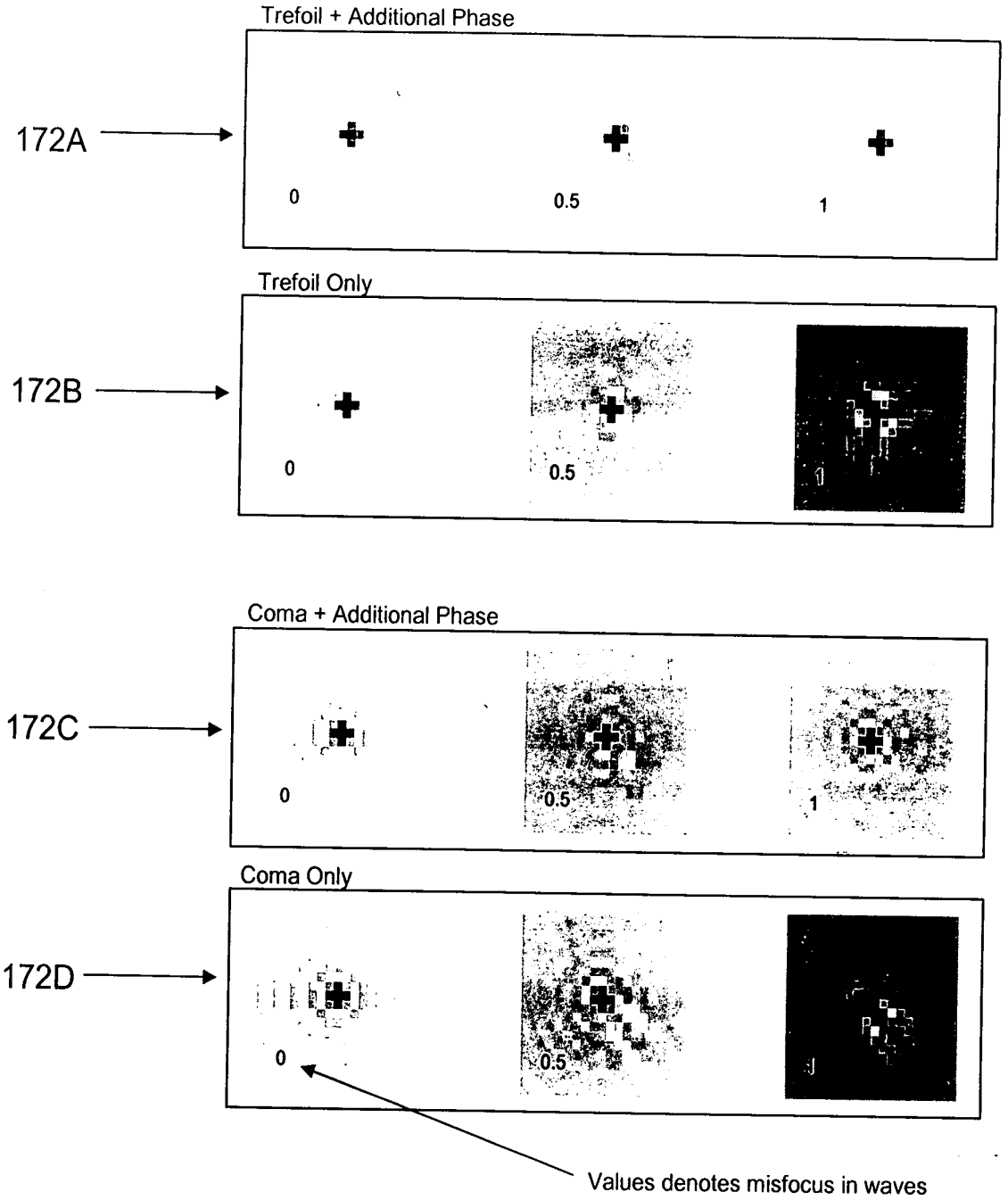


FIG. 17D


Trefoil + Additional Phase
172A
0
0.5
1
Trefoil Only
172B
0
0.5
1
Coma + Additional Phase
172C
0
0.5
1
Coma Only
172D
0
0.5
Values denotes misfocus in waves

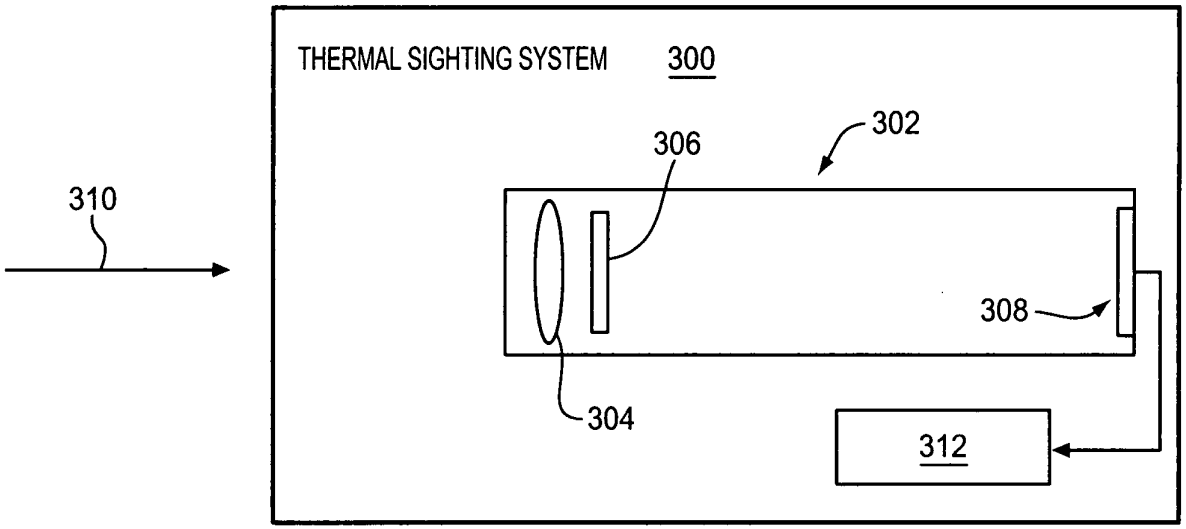
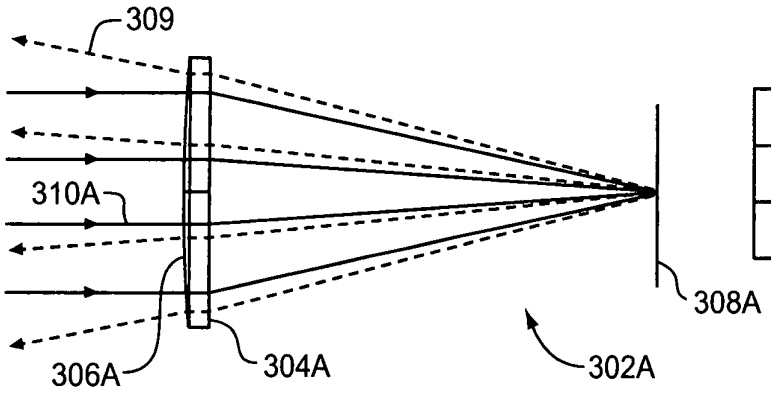
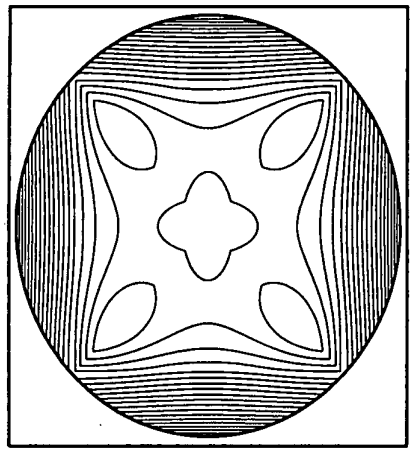


FIG. 18



Focal Length:	51.1 mm	FOV:	Axial
F/#:	2.5	Material:	Germanium
Wavelength:	10μm		

320



322

Constant Profile Path Surface:

Constant profile path optics, the paths being defined along the sides of a square

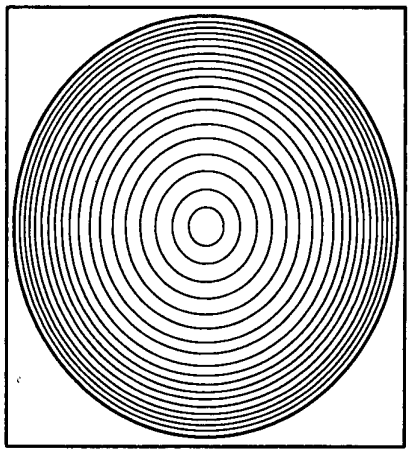
Along the paths form given by:

$C(x) = 3.9 \times 10^{-3} + 7.7 \times 10^{-5} x^2$, $|x| < 1$

Across the paths form given by:

$D(y) = 1.97 \times [\, 0.1\, y - 0.18\, y^2 + 1.02\, y^3 \,]$, $0 < y < 1$

324



Odd Asphere Surface:

Aspheric Terms:

Conic	-8.42
1st	9.35×10^{-4}
3rd	2.61×10^{-4}
5th	4.07×10^{-4}
7th	9.00×10^{-5}

FIG. 19

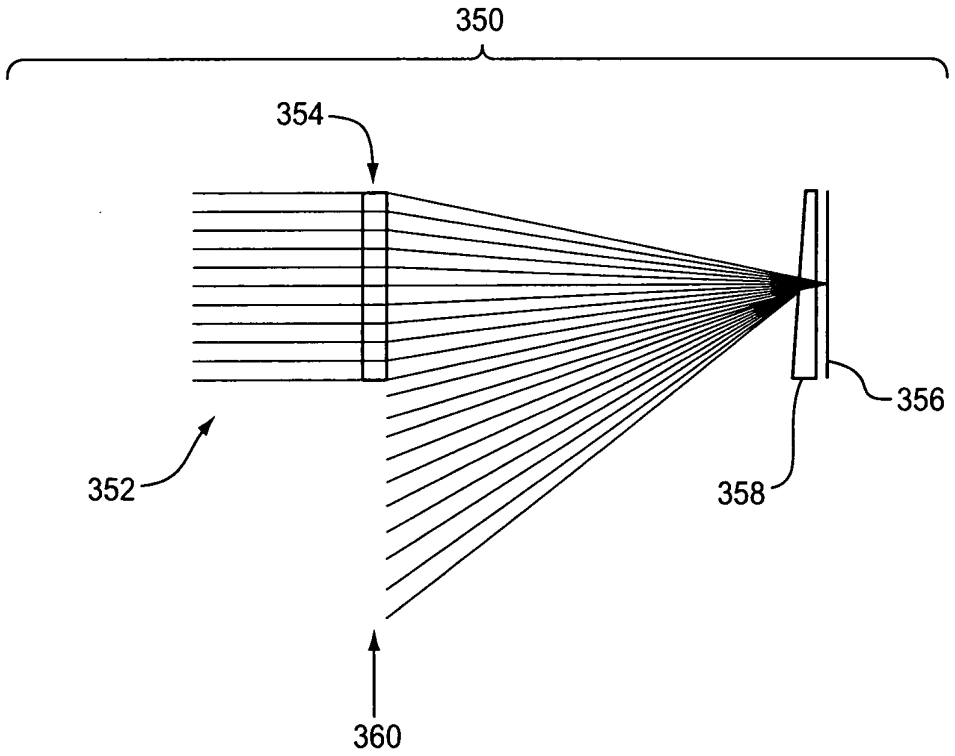


FIG. 20A

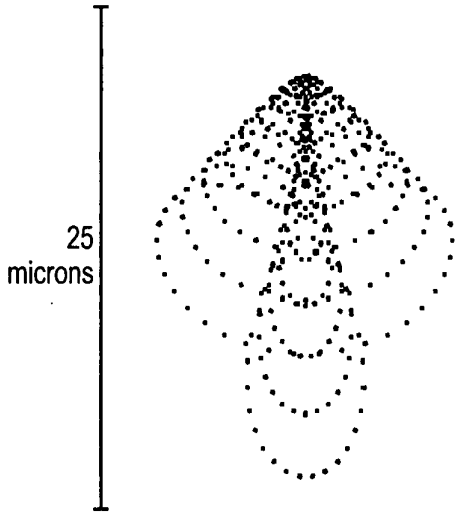


FIG. 20B

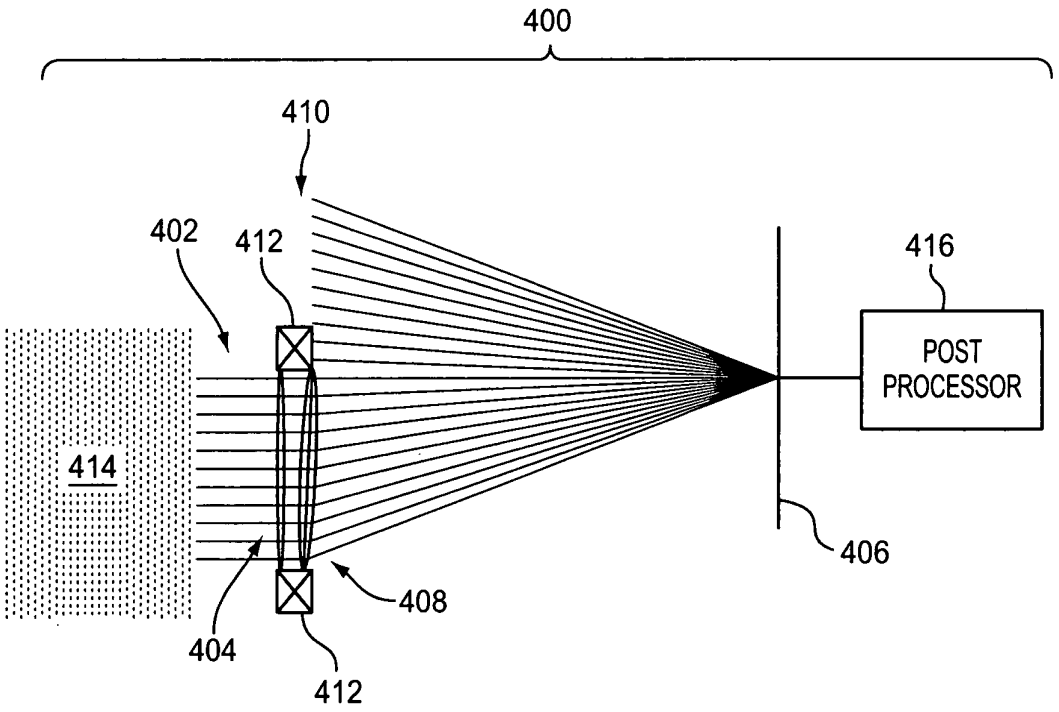


FIG. 21A

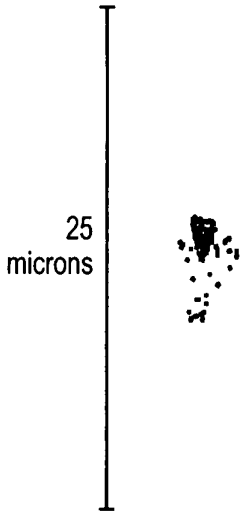


FIG. 21B

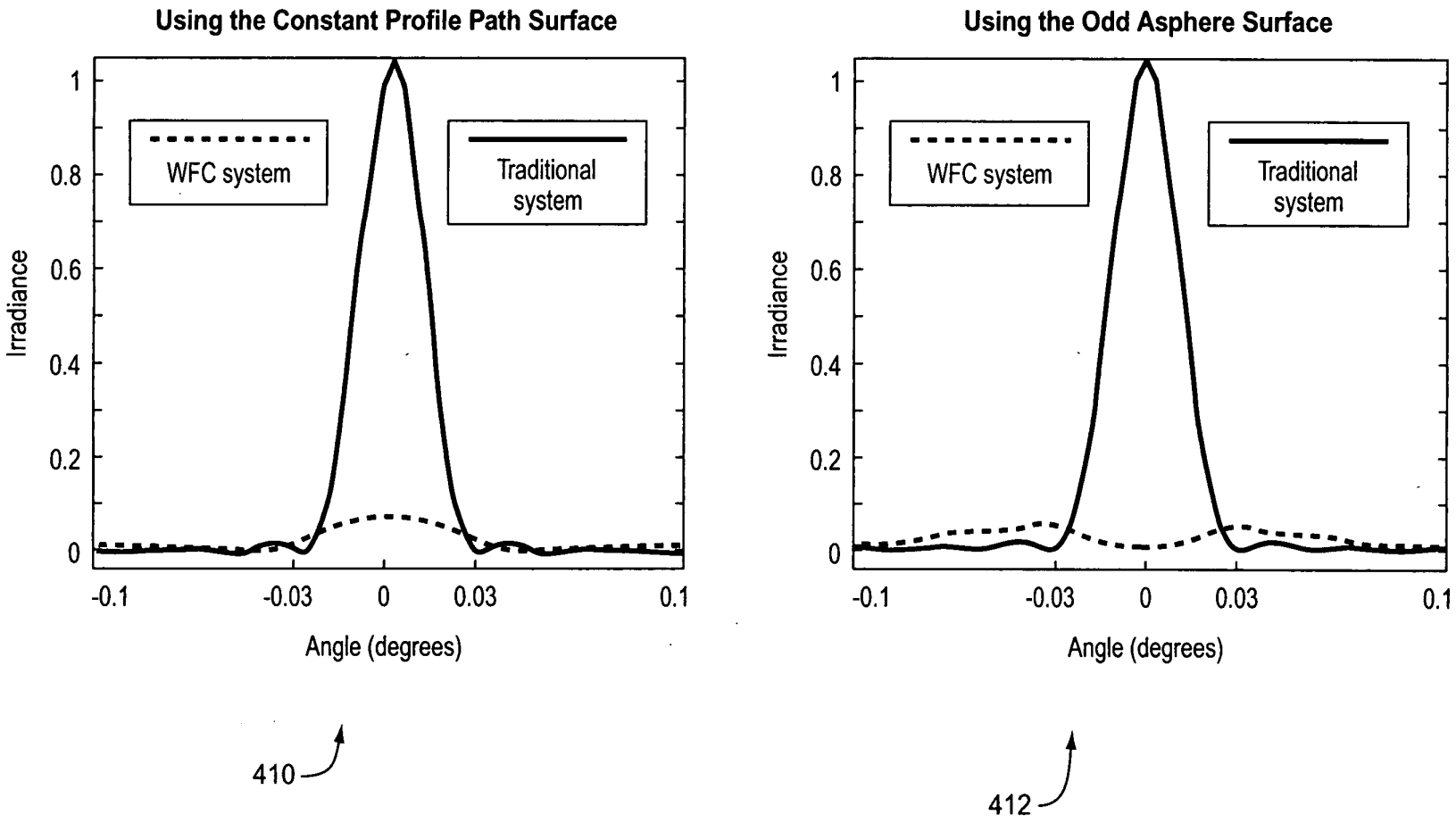

Using the Constant Profile Path Surface
Irradiance
1
0.8
0.6
0.4
0.2
0
WFC system
Traditional system
-0.1
-0.03
0
0.03
0.1
Angle (degrees)
410
Using the Odd Asphere Surface
Irradiance
1
0.8
0.6
0.4
0.2
0
WFC system
Traditional system
-0.1
-0.03
0
0.03
0.1
Angle (degrees)
412

FIG. 22

FIG. 22A


Reflection within 1/4 of the full width of the traditional beam
Traditional
Wavefront Coded
Relative power in dB
0
-10
-20
-30
-40
-50
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Angle

FIG. 22B

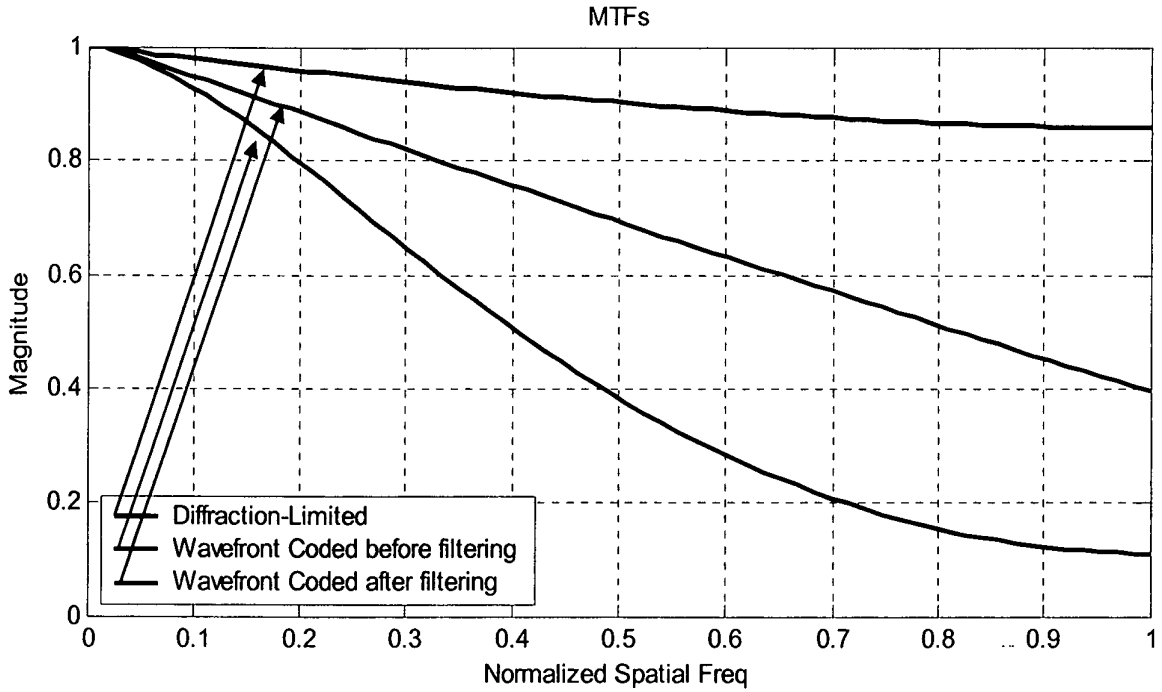

MTFs
Magnitude
Normalized Spatial Freq
Diffraction-Limited
Wavefront Coded before filtering
Wavefront Coded after filtering
0
0.2
0.4
0.6
0.8
1
0.1
0.3
0.5
0.7
0.9

FIG. 22C

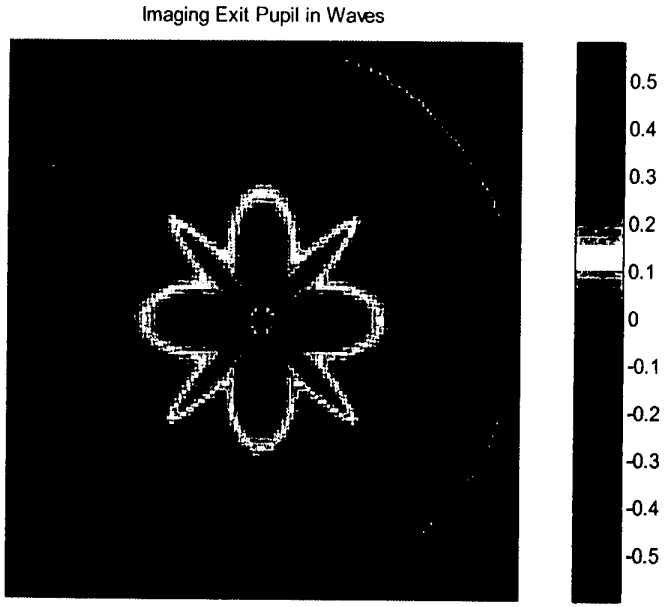
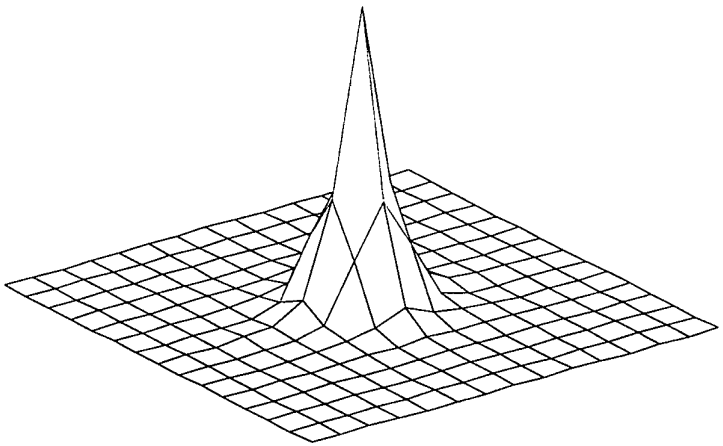


FIG. 22D



Mesh view

500

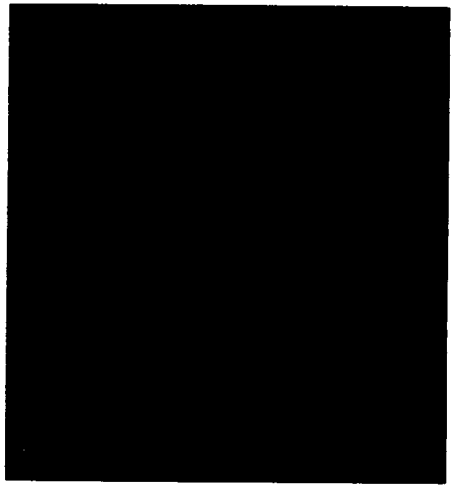


Image view

510

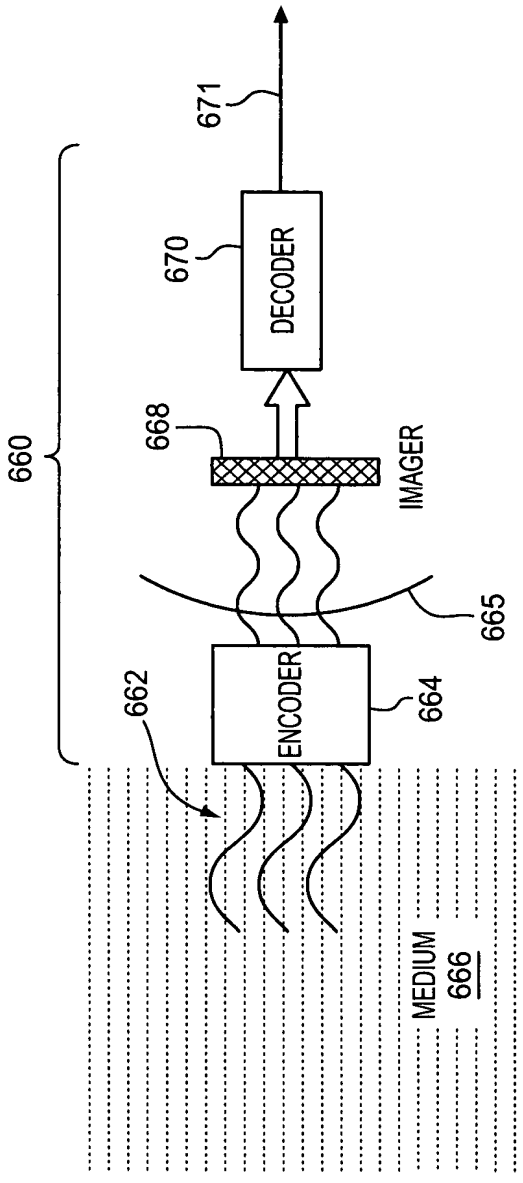

660
662
664
ENCODER
665
668
IMAGER
670
DECODER
671
MEDIUM
666

FIG. 23

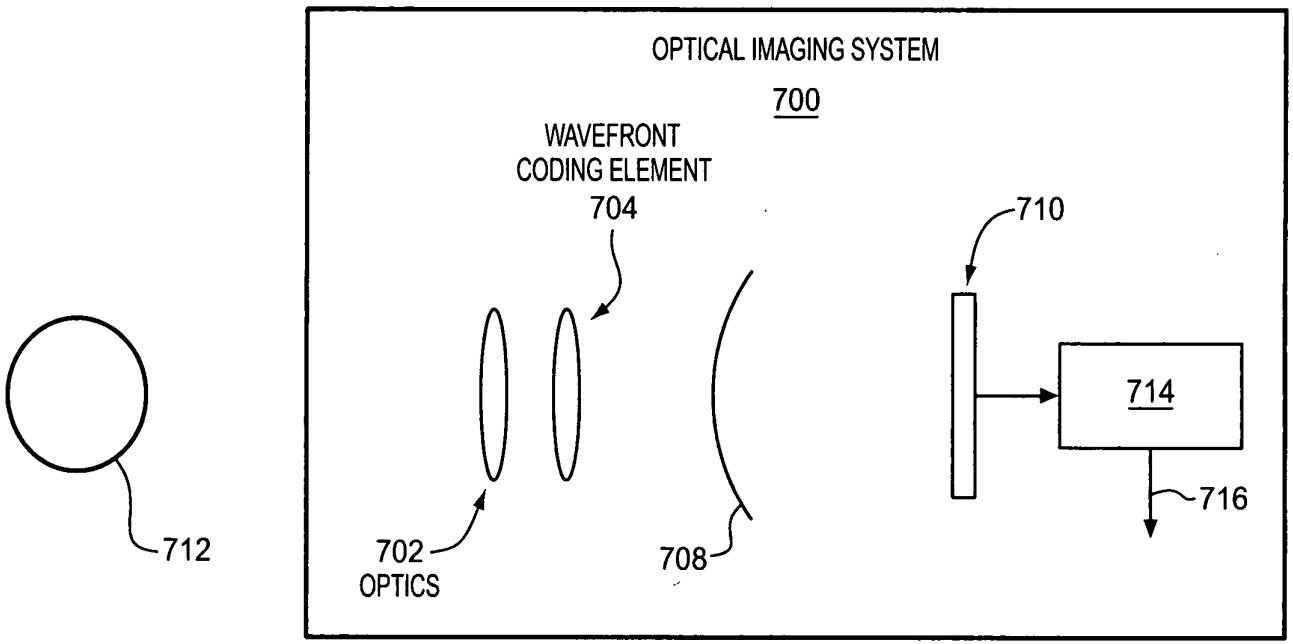

OPTICAL IMAGING SYSTEM
700
WAVEFRONT
CODING ELEMENT
704
710
714
716
712
702
OPTICS
708

FIG. 24

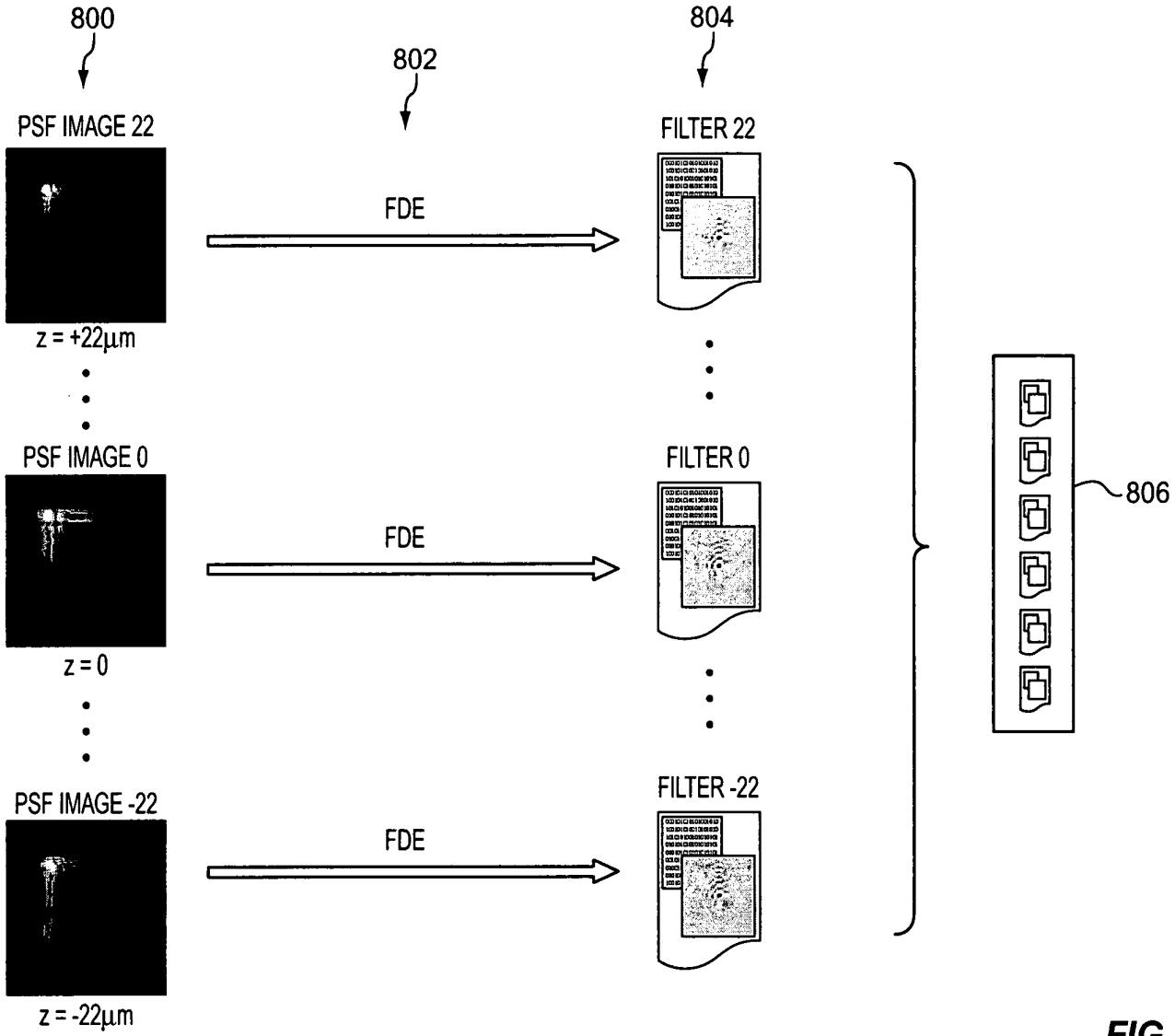

800
802
804
PSF IMAGE 22
FILTER 22
FDE
z = +22µm
PSF IMAGE 0
FILTER 0
FDE
z = 0
PSF IMAGE -22
FILTER -22
FDE
z = -22µm
806

FIG. 25

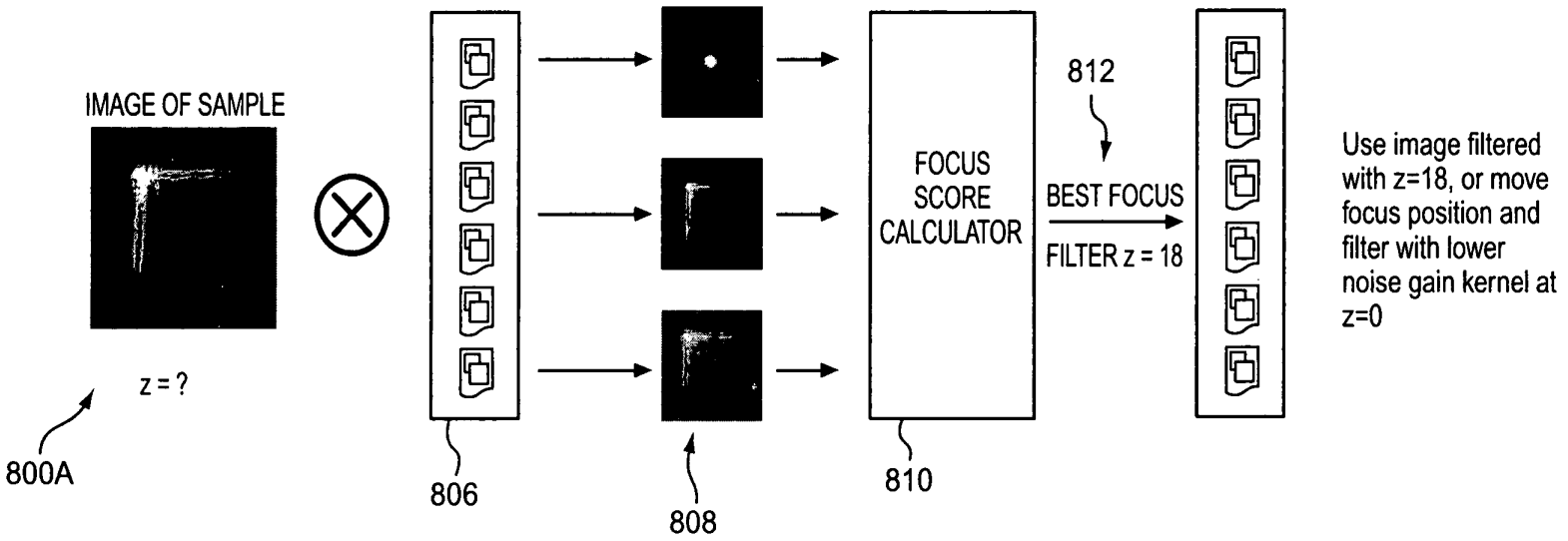


IMAGE OF SAMPLE
z = ?
800A
806
808
FOCUS SCORE CALCULATOR
810
812
BEST FOCUS
FILTER z = 18
Use image filtered with z=18, or move focus position and filter with lower noise gain kernel at z=0

FIG. 26

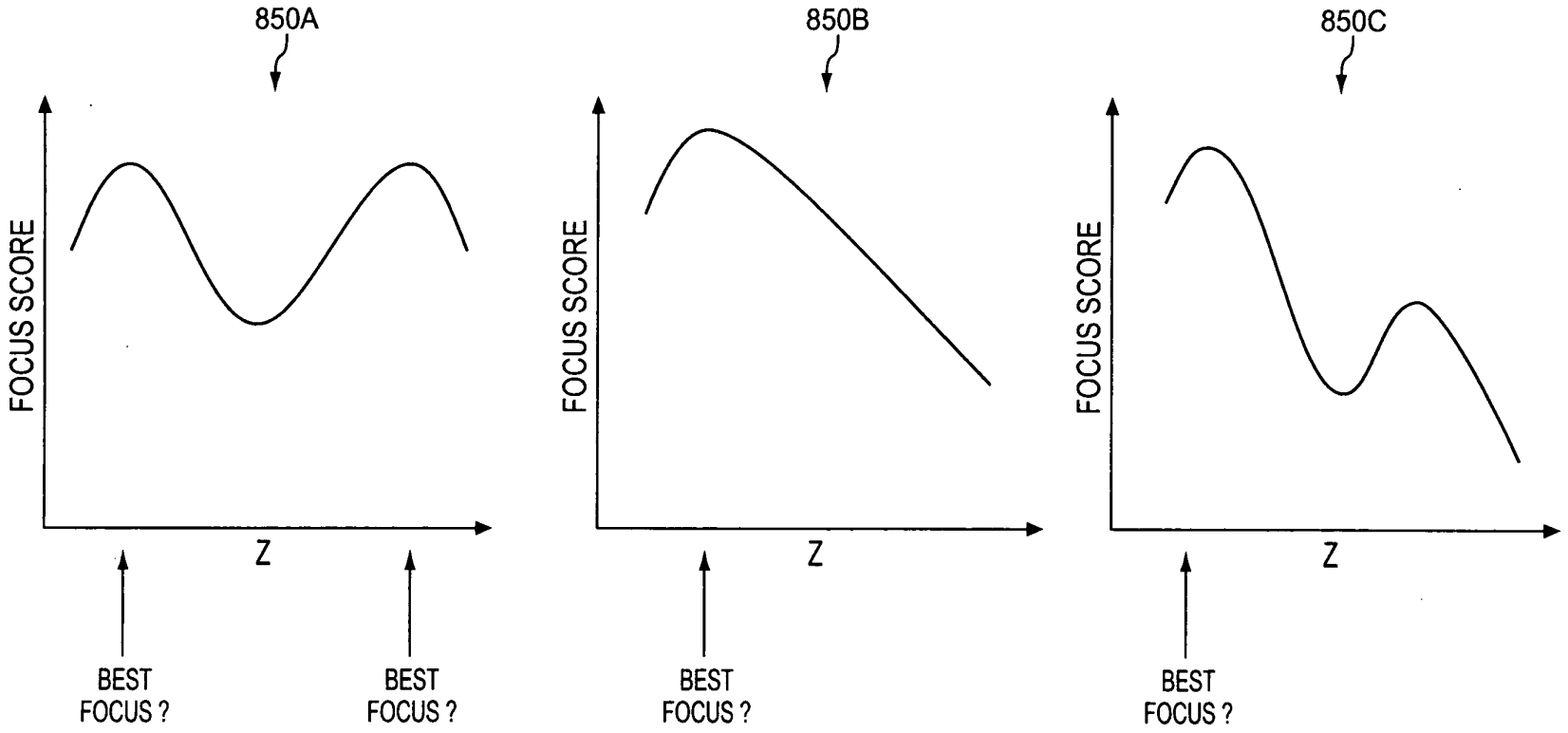

850A
FOCUS SCORE
Z
BEST FOCUS ?
BEST FOCUS ?
850B
FOCUS SCORE
Z
BEST FOCUS ?
850C
FOCUS SCORE
Z
BEST FOCUS ?

FIG. 27

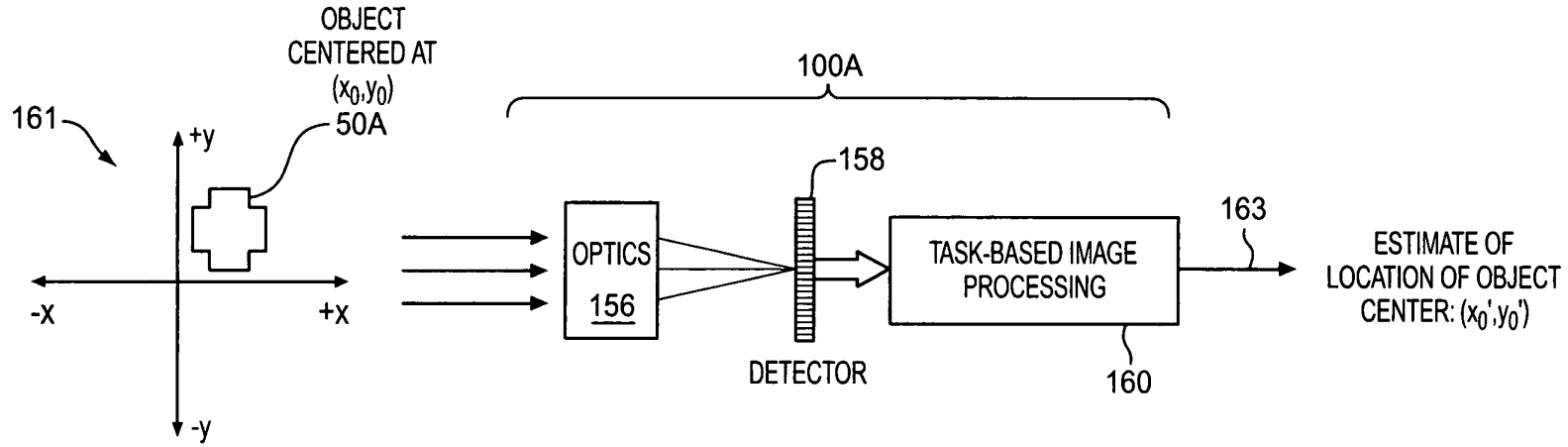


FIG. 28A

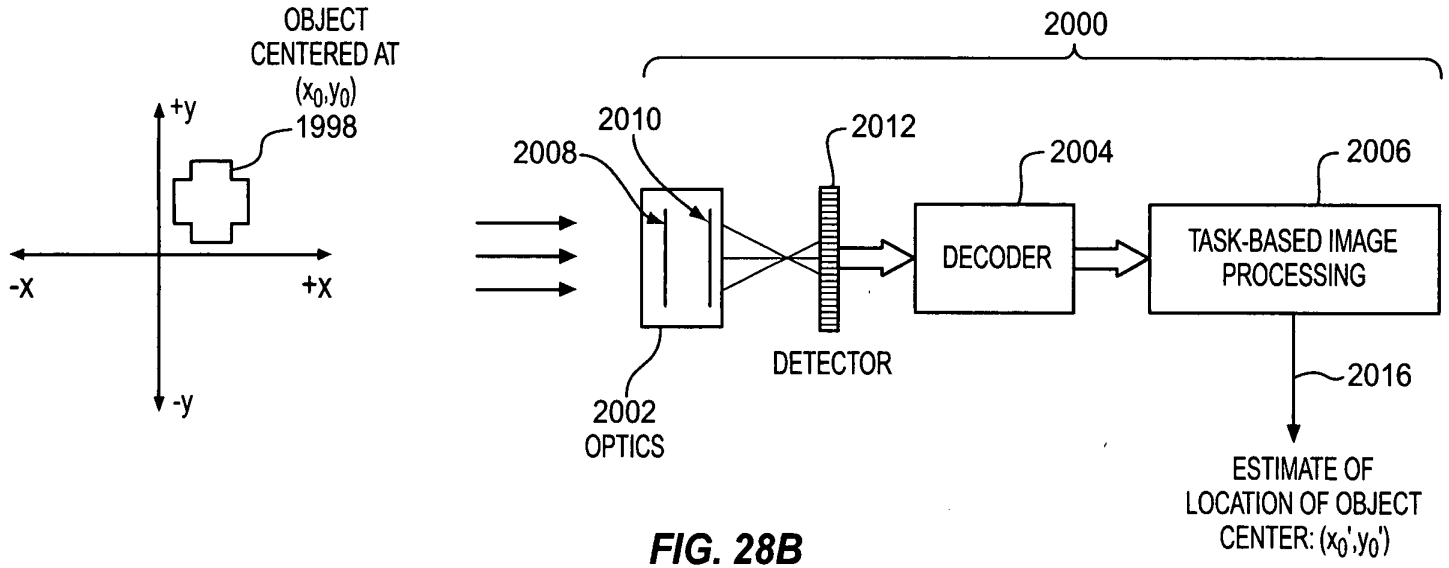


FIG. 28B

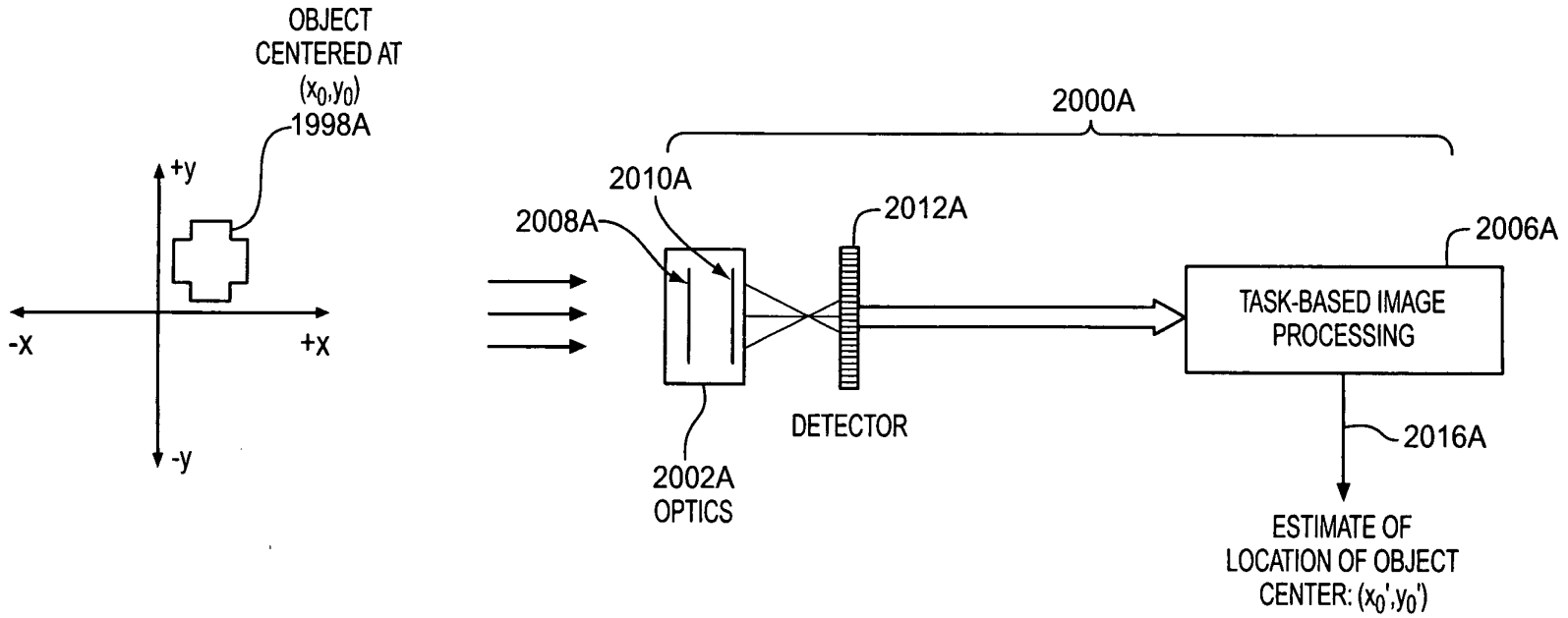

OBJECT
CENTERED AT
(x_0,y_0)
1998A
+y
-x
+x
-y
2000A
2010A
2008A
2012A
2006A
TASK-BASED IMAGE
PROCESSING
DETECTOR
2016A
2002A
OPTICS
ESTIMATE OF
LOCATION OF OBJECT
CENTER: (x_0',y_0')

FIG. 28C

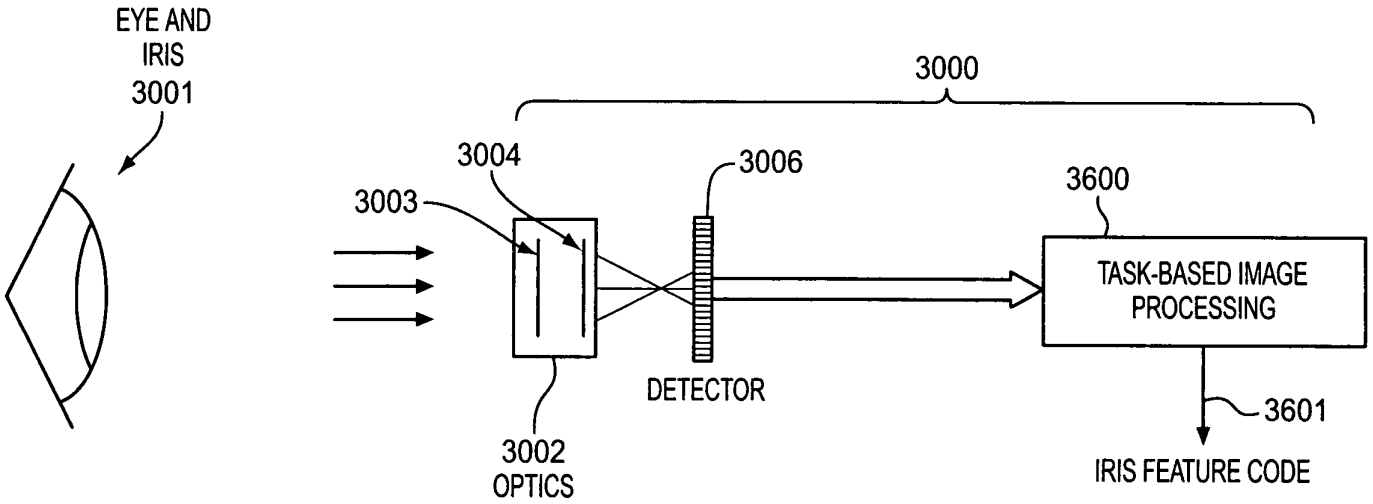

EYE AND
IRIS
3001
3000
3004
3006
3003
3600
TASK-BASED IMAGE
PROCESSING
DETECTOR
3601
3002
OPTICS
IRIS FEATURE CODE

FIG. 29